

The effect of construction activity on SPA waterfowl; a case study of the Abberton Reservoir Enhancement Scheme

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Abstract

Abberton Reservoir Essex, covering 4.85km², is a water storage reservoir and is designated a Ramsar site, Special Protection Area (SPA) and Site of Special Scientific Interest (SSSI). In order to meet predicted increases in water demand, large scale construction works to raise the water level of the Main Section and consequently increase the storage capacity, were undertaken between 2010 and 2013. Construction work primarily involved breaking out 12km (7.4 miles) of concrete apron and perimeter road, raising the main dam by 3.2m and extensive shoreline re-profiling. This provided a unique and valuable opportunity to explore the effects of disturbance associated with construction activity on the spatial distribution of waterfowl. Nine species, all SPA interest features, were chosen as a basis for this study, the dabblers *Anas strepera* (Gadwall), *A. clypeata* (Shoveler), *A. crecca* (Teal) and *A. penelope* (Wigeon), divers *Aythya fuligula* (Tufted Duck), *A. ferina* (Pochard) and *Fulica atra* (Coot), the herbivorous *Cygnus olor* (Mute Swan) and the piscivorous *Podiceps cristatus* (Great Crested Grebe).

As a consequence of both the reservoir's importance to waterfowl and planning regulations, extensive waterfowl surveys were undertaken pre-construction and used to assess and predict the potential impacts arising from construction activity. Findings were used in the overall consideration of the development, with analysis determining appropriate mitigation measures which were subsequently incorporated into project design to ensure there would be no adverse impacts upon the integrity of the site. Waterfowl surveys continued throughout the four year construction period (2010 – 2013) and together with four years of pre-construction survey data (2006 – 2009), were used to make comparisons between the two periods. The spatial and temporal distribution analysis formed the first part of this research and provided a baseline from which to assess the effects of disturbance. The second part used a novel approach to assess the extent and magnitude of disturbance from construction activity on the SPA waterfowl species, with changes in distribution assessed against baseline data and in relation to environmental variables including water depth, percentage cover of macrophyte and distance to the shoreline. Finally, the success of mitigation measures to ensure no adverse impacts and overall enhancement of the site were investigated with respect to the use of created displacement habitat by waterfowl and in relation to measures to minimise construction disturbance.

Numbers and distributions of all nine SPA species varied throughout the study period with numbers of waterfowl significantly increasing on the Main Section during construction. In contrast, although not directly subject to construction activity, the smaller Central Section suffered disturbance effects with the most significant decline seen for Tufted Duck. A general decline in over-wintering numbers of Tufted Duck was also observed. Findings show that the most important environmental variables determining distribution of the dabbling species was shallow water, with an increase in this habitat as a result of construction works, of particular benefit to Gadwall, Shoveler and Teal. Tufted Duck were found to be associated with deeper water and along with Pochard and Great Crested Grebe, were significantly related to areas containing high macrophyte cover.

While results show some disturbance responses and evidence for a 200m zone of disturbance impact, the continued success and maintenance of site integrity during construction is attributed to the size of the reservoir complex (which in itself acted as a mitigating factor). The employed mitigation measures were also deemed successful and instrumental in reducing the extent and magnitude of disturbance. This is the first time research has related the extent and magnitude of construction activity to the spatial distribution of protected waterfowl species and provided an assessment against substantial baseline data. This research provides evidence for a sensitive and science based approach to development where extensive monitoring has enabled the much needed, but often lacking, reporting of mitigation in relation to development induced impacts.

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Abbreviations and acronyms

AIC	Akaike Information Criterion
AOD	Above Ordnance Datum
BTO	British Trust for Ornithology
COType	Cluster type
DEM	Digital Elevation Model
DMC (1/2/3)	Distance to Machine Construction
DPC (1/2/3)	Distance to People Construction
DTC (1/2/3)	Distance to Total Construction
EIA	Environmental Impact Assessment
EOETS	Ely-Ouse to Essex Transfer Scheme
ES	Environmental Statement
FID	Feature Identity
GIS	Geographical information System
GLM	Generalized Linear Model
HH	Cluster of high values (cluster analysis)
HL	High value surrounded by a low value (cluster analysis)
KDE	Kernel Density Analysis
LH	Low value surrounded by high values (LH)
LL	Cluster of low values (cluster analysis)
Lrtest	Likelihood ratio testing
MAM	Minimum Adequate Model
NWG	Northumbrian Water Group
NB	Negative Binomial
PDA	Personal Digital Device
QP	Quasi-poisson
SAC	Special Area of Conservation
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
STIAA	Study To Inform an Appropriate Assessment
UK	United Kingdom
VIF	Variation Inflation Factor
WeBS	Wetland Bird Survey
χ^2	Chi square

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Chapter 1

Introduction and aims

Introduction

Wetlands provide one of the most important habitats in the world yet the loss and degradation of these vital ecosystems over the past few centuries has been exceptional and they continue to be threatened by agricultural intensification, pollution, climate change and development (Mander et al., 2007, Keddy et al., 2009, Guillemain et al., 2013, Sundar and Kittur, 2013, Beatty et al., 2014a, Clausen and Clausen, 2014, Curtiss and Pierce, 2016, Schneider et al., 2017).

Humans depend on the ecological integrity of wetlands as well as their ecosystem services (Schneider et al., 2017) and many artificial wetlands have an important function for the human population i.e. water storage or for recreational activities. It is not surprising however, considering the pressures, degradation and loss of natural wetland systems, that these man-made sites are becoming increasingly important for wildlife. In the UK, wetlands such as estuaries and reservoirs are extensively used by waterfowl during the moulting, migratory and overwintering periods and frequently hold numbers of national or international importance. These ecologically important wetlands are often designated as conservation areas and afforded strict legal protection which ultimately aims to restrict adverse impacts and promote positive change within the designated boundary (Selman, 2009). Conservation designations and protected sites include Special Protection Areas (SPAs) which are those sites considered of International Importance under the EU Directive on the 'Conservation of Wild Birds' (Council Directive 79/409/EEC, 1979). Legislation within the UK to comply with the Directive is incorporated into the Wildlife and Countryside Act 1981 as amended (HMSO, 1981). Under this act, the UK Government has a duty to designate any land a Site of Special Scientific Interest (SSSI) which they consider is of special interest. Many SPA and SSSI designated wetlands are also given the Ramsar designation under the Convention of Wetlands of International Importance (Ramsar Convention, 1971) which aims to conserve wetlands at an international scale and promote their sustainable use (Pritchard et al., 1992). At a landscape scale, nationally and internationally, these form a suite of protected sites which are more likely to support higher

numbers and a greater diversity of birds compared to isolated sites (Sundar and Kittur, 2013, Albanese and Davis, 2015).

Under these Directives, decision makers such as Government Authorities, Local Authorities and Statutory Bodies have certain obligations and responsibilities to ensure internationally important sites subject to planning or development proposals are considered with due care and attention. These obligations are achieved through the Environmental Impact Assessment (EIA) procedure (HMSO, 1999), whereby the impacts of a proposed development are identified and assessed. EIA's are accompanied by an Environmental Statement (ES) which includes an assessment of the predicted environmental effects as required by the European Union Council Directive to consider the impacts of a development on flora and fauna. A typical ES also identifies through its relevant chapters, any residual impacts arising from the development which then require compensation or mitigation. For wetlands, particularly those holding internationally important populations, mitigation or compensatory measures are typically designed to ameliorate the effects of habitat loss or disturbance arising from development.

The effects of disturbance upon waterfowl can be significant and the susceptibility and sensitivity of waterfowl species to disturbance has been correlated with foraging strategies, habitat requirements and type of disturbance (Cryer et al., 1987, Hill, 1992, Schummer and Eddleman, 2003, Yasué, 2006, Whitfield, 2007, Cutts et al., 2009, Wright et al., 2010, McLeod et al., 2013). The spatial and temporal distribution of migratory waterfowl naturally varies with changes in local and global climate, habitat suitability and food availability (Guillemain et al., 2000a, Bancroft et al., 2002, Norris and Marra, 2007, Briggs et al., 2012, Lehtikoinen et al., 2013) and should be distinguished from disturbance effects. The distance at which disturbance causes an effect such as a flight response has been used as a management tool, and to inform disturbance avoidance measures such as protective buffers and strategic screening or fencing (Rodgers and Smith, 1997, Ikuta and Blumstein, 2003, Durell et al., 2005, Glover et al., 2011, Livezey et al., 2016). Other mitigation measures include disturbance-free

zones, phased construction programmes, on-site habitat creation and where residual adverse impacts remain, compensatory habitat (Kolozsvary and Holgerson, 2016, Nunn et al., 2016).

However, the success of such mitigation and compensation measures has sparked interest and debate with literature reporting high rates of implementation, but low levels of success and monitoring (Zedler and Callaway, 1999, Drayson and Thompson, 2013, Bigard et al., 2017).

Furthermore, many mitigation measures provide recommendations without implying how successful they are likely to be, how they will be assessed and few studies test the reliability of a developments impact predictions or mitigation measures.

This presents difficulties for environmental managers, developers and regulatory bodies faced with designing and assessing projects of a large spatial extent and/or sensitive nature; particularly as there is a lack of formal guidelines for best practice in the restoration or creation of new habitats that specifically relate to waterbirds (Atkinson, 2001b). Additionally, but with some notable exceptions (Goss-Custard et al., 1991, Hill, 1992, Hill et al., 1997, Cutts et al., 2009, Pearce-Higgins et al., 2012), most disturbance based assessments relate to recreational disturbance, behavioural effects and the impact on individual fitness/survival, or are limited to coastal sites.

Abberton Reservoir, situated close to the coast in Essex, England, is a large water storage reservoir owned by Northumbrian Water Group (NWG). Covering 4.85km², it is of international importance to waterfowl and designated a Site of Special Scientific Interest (SSSI), a Special Protection Area (SPA) and a Ramsar site. In order to meet predicted increases in water demand, between 2010 and 2013 Abberton Reservoir was subject to The Abberton Scheme, an enlargement and enhancement project resulting in substantial construction works designed to raise the water level by approximately 3.2m and increase the capacity by 58%. The Abberton Reservoir Enhancement Scheme in its entirety represents one of the largest planning applications in UK history and therefore, presents a unique opportunity to assess, across a large spatial and temporal extent, the effects of construction disturbance on internationally important waterfowl populations. Construction activity at Abberton

Reservoir spanning a four year period is mapped, ranked and its impacts upon Abberton Reservoir SPA waterfowl species determined.

This study is the first assessment that relates magnitude of construction disturbance to the spatial distribution of individual waterfowl species and provides an assessment against environmental variables and baseline data. Furthermore, the success of mitigation measures incorporated into the Abberton Scheme are evaluated and collectively, the outputs of research represent and contribute towards an advancement of knowledge in this area of research.

Aims

Responses to disturbance impact and the effectiveness of mitigation measures are intrinsically linked and monitoring and auditing is essential if impact predictions and mitigation strategies are to be used as a reference in ecological assessment. This study ultimately aims to assist in determining the best approach to development on important waterfowl sites, to address the lack of analysis surrounding the impacts of construction disturbance on individual species and provide an examination of the success of implemented mitigation measures.

The objective of this study can be categorised into four main aims:

1. Conduct a comparative assessment of the spatial and temporal distributions of Abberton Reservoir SPA waterfowl species in years prior to construction (2006 – 2009) and in years during construction (2010 – 2013) (Chapter 4).
2. Determine the effects of construction activity associated with the Abberton Scheme on Abberton Reservoir SPA waterfowl aggregations and individual species with reference to environmental conditions, and provide an assessment against baseline data (Chapter 5).
3. Determine species sensitivities to different types and magnitudes of construction disturbance (Chapter 5).

4. Determine the effectiveness of the Abberton Schemes mitigation measures and impact predictions through:
 - a. Analysis of the spatial and temporal use by Abberton Reservoir SPA waterfowl of the created displacement habitat at the Western Section by (Chapter 5) and;
 - b. Assessment of the incorporated programme and habitat design features designed to mitigate disturbance impacts (Chapters 5 and 6).

Chapter 2

Literature review and background information

2.1 Wetlands and waterfowl

Wetlands are essential to waterfowl and many species require a range of habitats and conditions that often change with their annual life cycle. This is particularly noticeable as they move between breeding and wintering grounds whereby migration involves emigration (departures) and immigration (arrivals), and in Europe, tends to be north-south in the autumn and south-north in the spring (Cramp and Simmons, 1977). Many migratory waterfowl spend the winter in Great Britain which lies along the path of the East Atlantic flyway; an important ecological connection between breeding grounds in the Arctic with wintering sites in Western Europe and along the western seaboard of Africa (Roomen et al., 2015). In addition to providing overwintering habitat, the UK acts as a crucial stop-over along the migratory route enabling birds to replenish their energy and fat reserves. Coastal regions in particular, are extensively used by migratory waterfowl with influxes often in response to cold weather conditions on breeding grounds as birds move to seek cold weather refuges; sites where the selective pressures of winter harshness are reduced (Baillie, 1986, Musilova et al., 2015). As a consequence, and reflecting the importance of UK wetlands to waterfowl, many sites, especially those situated on the south-east coast of Britain, are legally protected and contribute to the global and European network of ecologically important wetlands (Figure 2.1). The legislation and designations pertaining to important wetlands are outlined in Section 2.3.1.

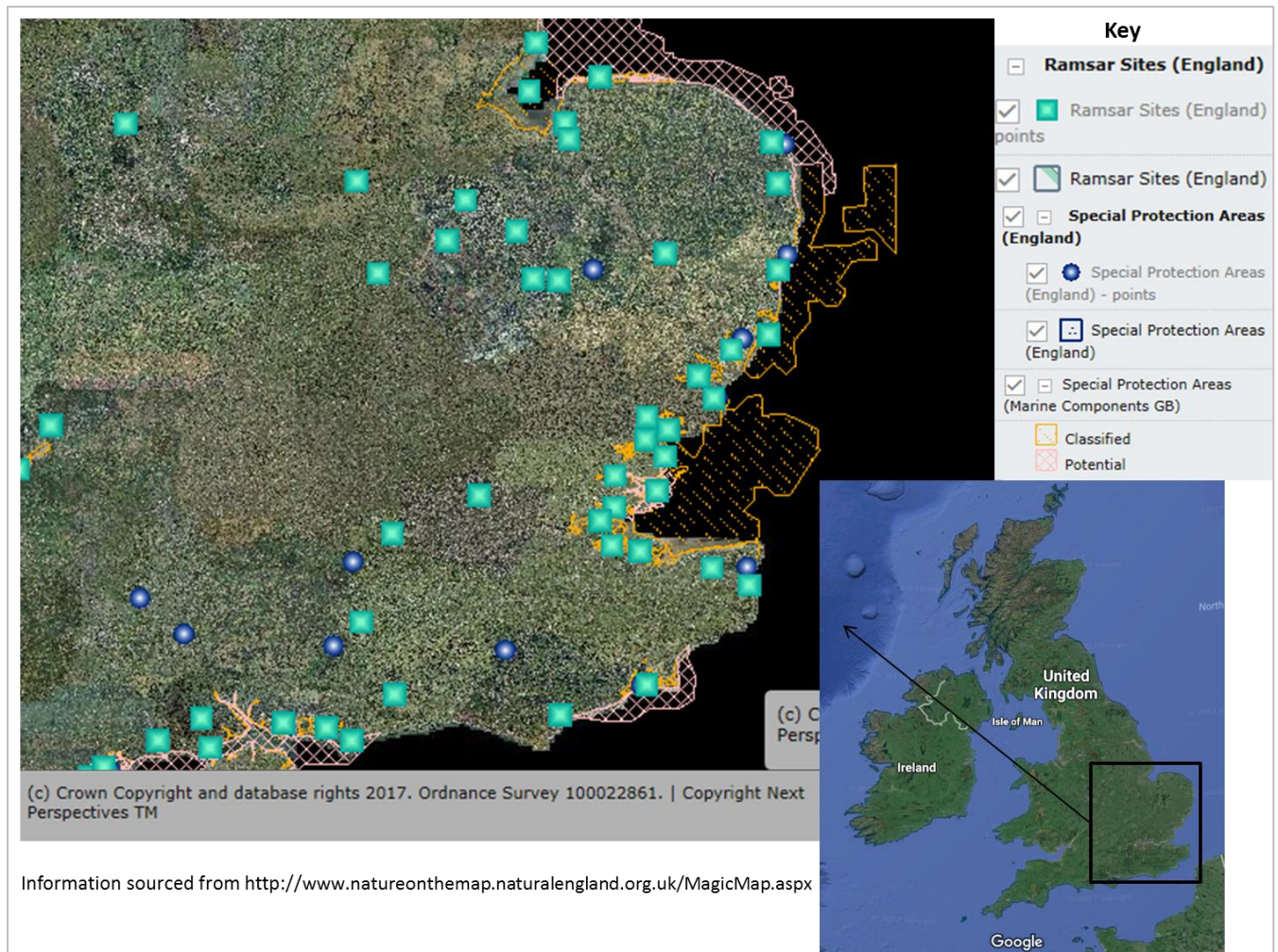


Figure 2.1: Locations of important wetlands within south-east England. Sites highlighted on the map are those with Ramsar wetland and Special Protection Area (SPA) status. Information obtained through Magic Map (Natural England, 2002).

Whilst high numbers of waterfowl are largely associated with the winter migratory period, the UK also holds substantial numbers of breeding and moulting waterfowl (Pritchard et al., 1992). Unlike other birds, which shed their flight feathers throughout the year, waterfowl shed all their flight feathers at the end of the summer in an annual moult which renders them flightless for up to four weeks. The regrowth of flight feathers is an energetically costly stage during which time they are particularly vulnerable and susceptible to starvation, predation and the effects of disturbance (Portugal et al., 2009, Ndlovu et al., 2017).

2.2 Threats and effects of disturbance

2.2.1 Disturbance stimuli and habituation

Disturbance can be defined as the disruption of the normal activity or physiology of wildlife in the proximity of an agent such a person or vehicle (McLeod et al., 2013). Disturbance stimuli present as many forms and can occur as a result of natural processes such as predation or as a result of human activity. Evidence suggests that responses elicited by waterfowl to non-human disturbance such as birds and mammals are lower than responses to human disturbance (Hockin et al., 1992a, Schummer and Eddleman, 2003, Pease et al., 2005, Martín et al., 2015). This raises concern for conservationists and site managers given that the majority of our important wetland sites are increasingly under pressure from human activity (Guillemain et al., 2002a, Ma et al., 2009, Matchett and Fleskes, 2017, Schneider et al., 2017).

Responses by waterfowl from lethal activities such as shooting are understandably severe, although non-lethal activities such as walking are also detrimental. This is because from an evolutionary perspective, human interference is perceived similarly to predation risk (Frid and Dill, 2002). This perspective not only has implications in terms of site development, but also in considering the impacts arising from recreational activities, the effects of which are well documented (Cryer et al., 1987, Burger, 1998, Finney et al., 2005, Linaker, 2012, Dinges et al., 2015). Although there is some debate as to which activity produces the greatest disturbance response in birds, one consistent finding is that the response displayed by a bird is inversely related to the distance between the bird and disturbance stimuli (Pease et al., 2005, Western et al., 2012).

The magnitude with which a bird responds to disturbance has also been linked to intensity, duration and type of disturbance activity (Hill, 1992, Whitfield et al., 2008, Cutts et al., 2009). Long-term studies on *Pluvialis apricaria* (Golden Plover), breeding close to the Pennine Way, an intensively used footpath, assessed responses of birds to intensity and extent of human activity. Following path

resurfacing which reduced the frequency with which people strayed, the avoidance zone changed from 200m to 50m (Finney et al., 2005). This may have been due to a more predictable disturbance pattern resulting in a degree of habituation. Indeed it has been suggested that habituation to disturbance may be considerable, and occur over a relatively short period of time (Hill, 1992), particularly to lower, more continuous levels of disturbance and repeated exposure (Ikuta and Blumstein, 2003, Webb et al., 2010). Other studies however, have found no evidence of habituation (Marsden, 2000, Martín et al., 2015), therefore it is likely that habituation is extremely variable and dependent upon species, site conditions and disturbance stimuli. Ultimately, individuals that do not habituate and are unable to find alternative habitat may leave the area permanently causing effects equivalent to that of habitat loss (West et al., 2002).

2.2.2 Disturbance from construction activity

Compared with recreational activity, there is less available information assessing the effects of disturbance on waterfowl resulting from construction activity, particularly on large sites supporting internationally important populations. This is not surprising given the strict protection e.g. Ramsar or SPA status, surrounding such sites. As a result, much of the available literature originates from estuarine studies; areas increasingly under pressure from development and climate change (Durell et al., 2006, Mander et al., 2007, Clausen and Clausen, 2014). Construction works associated with such large scale development or infrastructure have one advantage in that the longer term effects of disturbance can be observed. They are also typically subject to enhanced ecological monitoring which provides knowledge usually absent from the majority of studies where numbers using a site in the absence of disturbance, is generally not known (Gill, 2007). One such study, carried out over an 11 year period, assessed waterfowl using mudflats adjacent to construction work at Cardiff Bay in South Wales (Burton et al., 2002). Models showed construction work to significantly reduce the densities of five species of waterfowl suggesting that sustained construction work may have a longer term effect, and that some species avoid areas adjacent to construction activity (Burton et al., 2002).

Disturbance from construction activity can occur in many forms; the most studied of which relates to visual disturbance arising from humans or machines. Although there is some variation within the literature, higher disturbance responses shown by waterfowl have been associated with pedestrians compared with vehicles (Pease et al., 2005). Construction activity and vehicle movements can also emit loud noises, many of which are impulsive, occurring over a relatively short time period and at a range of frequencies. Disturbance to waterfowl from construction noise can be significant although differences in background noise, types of disturbance and the response are likely to vary substantially between species, across sites and for different types and levels of sound (Wright et al., 2010). In noise experiments on waterfowl within the UK, Wright et al. (2010) found that birds subject to intentional noise disturbance showed a range of behavioural responses, with the probability of more energetically costly responses i.e. flight, associated with increasing noise levels.

Given the view that pedestrians evoke a strong disturbance reaction in waterfowl, when assessing the effects of disturbance resulting from construction activity, it is necessary, albeit difficult, to differentiate between those attributed to construction and those attributed to the presence of humans (Hill, 1992, Wright et al., 2010). Whilst the view that human presence causes the most significant disturbance to waterfowl is widely supported, it was construction activity, not pedestrians that were found to be the reason for site evacuation in *Aythya ferina* (Pochard) and *A. fuligula* (Tufted Duck) at Salford Docks, a redevelopment site in Manchester, UK (Marsden, 2000). This may however have been a consequence of more random, startling construction activity at the site compared with more consistent pedestrian disturbance (see habituation above). Whilst Marsden did not find evidence for habituation to construction activity, the study did find evidence of short-term flexibility in response to disturbance whereby the birds tended to stay onsite if they had stayed the previous day. Furthermore, birds that were disturbed in the morning tended to evacuate the site, yet those that had avoided evacuation in the morning, were more likely to remain *in-situ* when subsequent disturbance occurred in the afternoon. This suggests an element of habituation to disturbance or a level of tolerance by those birds that were not displaced.

2.2.3 Consequences of disturbance to waterfowl

The consequences resulting from disturbance are usually indirect and relate to reductions in reproductive success, fitness, feeding and increased competition. Birds moving out of the immediate vicinity of disturbance will increase the density elsewhere. Consequently, resources in these undisturbed areas may then deplete more rapidly or be made less profitable by interference competition (West et al., 2002). This is supported by Gill, 2007, who explains that at a population scale, any decline to an area should be considered in terms of density-dependence and not just as a direct result of disturbance.

The effects of disturbance on a population may be most dramatic during migration and over winter when energetic demands and bird densities are much higher. Reduced fitness and even death may occur if individual demands are not balanced with the cost of disturbance. This has been shown with modelling work carried out on *Haematopus ostralegus* (Oystercatcher), where critical thresholds for frequency of disturbance varied depending on feeding conditions (Goss-Custard et al., 2006). Effects of disturbance may also impact upon an individual's breeding success. In a review of over 40 papers, (Hockin et al., 1992) found that in 36 of them, human-induced disturbance reduced breeding success by causing nest abandonment and increased predation through reduced nest attendance.

Observations of waterfowl on a disturbed site may conclude that an individual or population is unaffected by the disturbance stimuli. Many studies examining the effects of visual disturbance look at alertness and flight initiation distances (Finney et al., 2005, Webb et al., 2010, Glover et al., 2011, Dear et al., 2014), assuming that the least sensitive birds are those that remain *in-situ* until the source of disturbance is close. It has been suggested however, that birds displaying this apparent tolerance may in fact be those with the most to lose from changing their behaviour and are unable to compensate for the costs of flying away (West et al., 2002, Beale and Monaghan, 2004). Should this be the case, and birds remain faithful to a site in the presence of disturbance, they may supplement their food intake to fulfil their energetic requirements by feeding at night. Nocturnal

feeding patterns are known to occur in diving species such as Pochard and Tufted Duck (Marsden, 2000, Evans and Day, 2001). However, on disturbed sites this behaviour has been observed in other species less associated with nocturnal feeding (Guillemain et al., 2002a, Briggs et al., 2012).

2.2.4 Effect of environmental variables upon waterfowl

When assessing the impacts of disturbance on waterfowl, it is important to consider other factors that may be affecting their susceptibility and determine if they are displaying any spatial preferences in response to environmental variables. As such, a key consideration in predicting and evaluating the effects of disturbance on waterfowl is their immediate and surrounding habitat. Environmental variables known to influence waterfowl include food availability, temperature, water depth and availability of sheltered and safe roosting habitat (Bancroft et al., 2002, Gawlik, 2002, Briggs et al., 2012, Lehtikainen et al., 2013, Tavares et al., 2015).

Aquatic plants are generally those referred to as submerged (macrophyte), emergent and marginal and their distribution within a water body is influenced by factors such as light attenuation, turbidity, flow velocity and dissolved organic carbon (Lacoul and Freedman, 2006, Alahuhta et al., 2013, Lázár et al., 2015, Schneider et al., 2015). They are fundamental components within a wetland ecosystem, making wetlands one of the most productive systems on the planet and they provide important habitat and food for macro-invertebrates, fish and waterfowl (Dennison et al., 1993, McKinstry and Anderson, 2002). The association between waterfowl and aquatic vegetation has long been known with lower numbers of waterfowl linked to periods of low macrophyte cover and differences between herbivores and omnivores observed (Hansson et al., 2010). Studies have differentiated between dabbling and diving waterfowl in regards to habitat preferences and feeding patterns, with differences mainly attributed to waterfowl morphology (Guillemain et al., 2000a, Bancroft et al., 2002). Dabbling waterfowl tend to prefer shallow water habitat which enables them to access submerged macrophytes while diving waterfowl (members of the genera *Aythya* and *Bucephala* for example), are not constrained to the shallows and can access food resources available

in deeper water. Indeed, the distribution of diving waterfowl has been shown to positively correspond with water depth (Baschuk et al., 2012), although there are also observations of both dabbling and diving bird abundance reducing with increasing water depth (Tavares et al., 2015). The influence of water depth upon waterfowl distribution relates not only to a bird's feeding requirements, but also to the provision of safe roosting habitat which may be particularly important during the moulting period when waterfowl are flightless. This may be partly responsible for the differences observed within literature although each site will differ and should be assessed relative to its species and environmental conditions.

2.2.5 Species sensitivities to disturbance

Different species and species groups show variation in sensitivity to disturbance. The most sensitive species reported from one study assessing disturbance from recreational activities were the dabbling species *Anas crecca* (Teal) and *A. clypeata* (Shoveler). However, *Bucephala clangula* (Goldeneye), a diving species was also found to be particularly sensitive. *Cygnus olor* (Mute Swan), Pochard and Tufted Duck and *A. platyrhynchos* (Mallard) were found to be the most tolerant (Tuite et al., 1984). In response to the presence of anglers, Cryer et al., 1987, reported no change in overall numbers of wildfowl although *A. penelope* (Wigeon), Pochard and Mallard all increased their feeding at the start of the closed season. The spatial distribution of these three species also changed, with the most notable effect observed for Wigeon, whose distribution changed from the centre of the reservoir during fishing to the grassy shores when angling ceased. Sensitivity to disturbance in Wigeon and other dabbling ducks such as *A. strepera* (Gadwall) is also reported in experimental disturbance studies assessing responses to anthropological disturbance stimuli (Pease et al., 2005). These studies support the view that herbivores such as Wigeon which spend long periods of time feeding during the day are particularly sensitive to disturbance (Hockin et al., 1992b). Flocking species are also considered to be more susceptible which is attributed to the flock's reaction time being dependent upon the reaction of the most alert or sensitive bird (Western et al., 2012).

2.3 Legislation and the Environmental Impact Assessment (EIA)

procedure

2.3.1 Legal protection for wetland sites

Due to the extensive use of wetlands by waterfowl, sites holding nationally or internationally important populations are often designated as conservation areas and offered a high degree of legal protection. An area qualifying for Special Protection Area (SPA) status is one considered of International Importance under the EU Directive 79/409 on the 'Conservation of Wild Birds' (informally known as the Birds Directive). Examples of these sites are shown for south-east England (Figure 2.1). The Birds Directive was adopted on 2nd April 1979 and requires member states to identify areas to be given special protection for rare or vulnerable birds (the Annex 1 listed birds, Article 4.1) and to safeguard regularly occurring migratory species (Article 4.2). SPAs and Special Areas of Conservation (SACs) make up the European Union network of conservation sites established under the EC Habitats and Birds Directives and form a network of protected areas known as Natura 2000. Legislation to implement the Habitats and Birds Directives within the UK is incorporated into the Wildlife and Countryside Act 1981 (amended 1985). Under this Act, the UK Government has a duty to designate any land an SSSI which they consider is of special interest by reason of its flora, fauna, geological or physiographical features. SSSI designation provides statutory protection for the UKs best sites with protection and management improvements introduced by the Countryside and Rights of Way Act 2000 (in England and Wales).

Many important UK wetlands, particularly those designated as an SPA are also given the Ramsar designation under the Convention of Wetlands of International Importance, drafted in Ramsar, in Iran 1971. The Ramsar Convention is an intergovernmental treaty providing the framework for national and international cooperation for the wise and sustainable use of wetlands throughout the world. The UK signed the convention in 1973 and it was ratified by UK parliament in 1976. The

Ramsar Convention is the most widespread and commonly accepted conservation treaty devoted to wetlands with two of the nine qualification criteria based on waterbirds (Sayoud et al., 2017).

Migratory waterfowl are changing their distributions in response to climate change, further highlighting the importance of a network of protected wetlands for waterfowl (Mander et al., 2007, Beatty et al., 2014a, Pavón-Jordán et al., 2015, Roomen et al., 2015, Uden et al., 2015).

2.3.2 Development and the EIA process

Obligations to comply with the Habitats and Birds Directives and to assess the ecological impacts arising from a proposed development on important sites are achieved through the Environmental Impact Assessment (EIA) procedure. The EIA procedure is used by decision makers to inform planning decisions and aims to safeguard the environment and its components from any major effects caused by a proposed development. EIAs are carried out early in the design phase in order to assess potential impacts and build mitigation and recommendations into the project without incurring unnecessary time or financial costs.

To comply with the Town and Country Planning (Environmental Impact Assessment), (England and Wales), Regulations 1999, planning applications are accompanied by an EIA report – the Environmental Statement (ES). The ES includes an assessment of the predicted environmental effects as required by the European Union Council Directive to consider the impacts of a development on flora and fauna. The ES also identifies any likely significant adverse effects and ways in which these can be avoided or mitigated for. Following mitigation measures, should any remaining residual impacts be identified and no other satisfactory alternative to the project demonstrated, compensation is required. However, the ES is not a legally binding document and unless mitigation measures are included and secured through planning conditions or Section 106 Agreements (held between the Local Authority and the developer), there is no legal requirement for them to be implemented (Drayson and Thompson, 2013). The main processes that occur during an EIA are outlined in Figure 2.2.

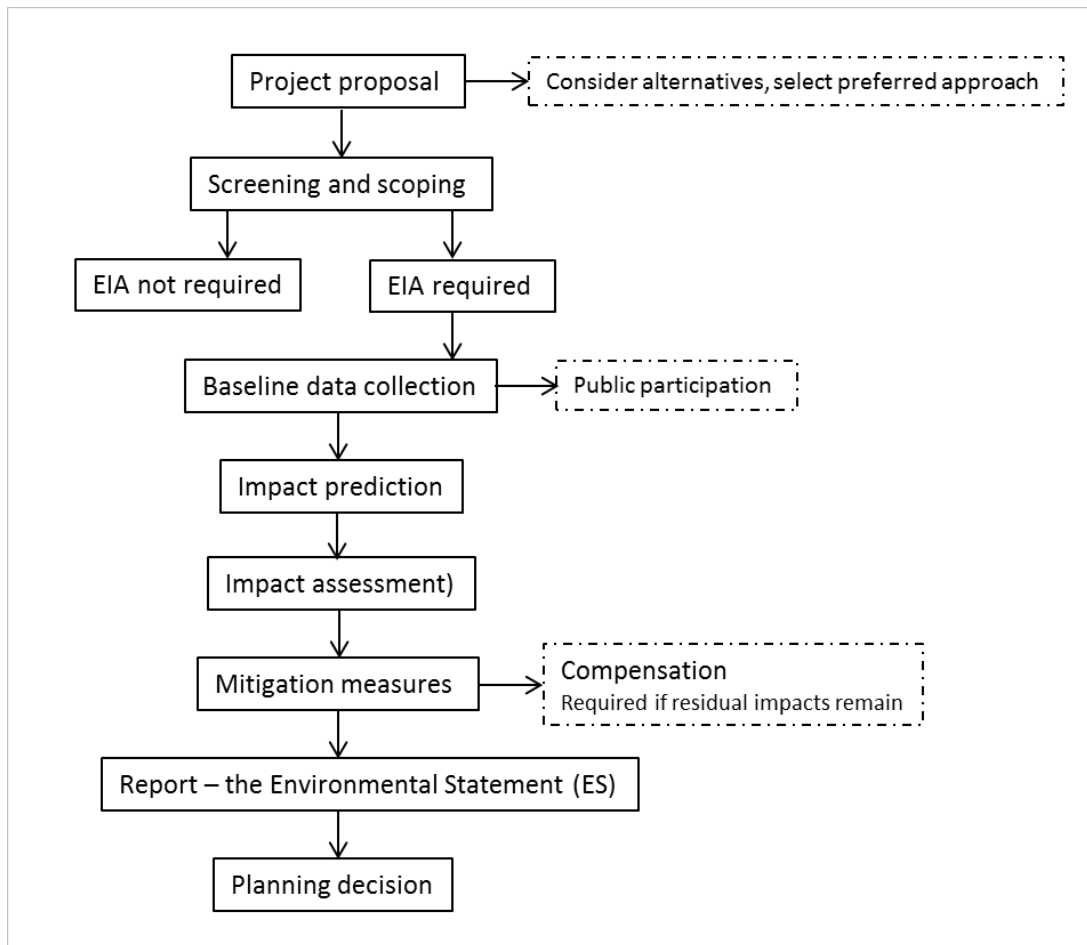


Figure 2.2: Flow chart outlining the steps taken in an EIA.

2.4 Mitigation and compensation

Mitigation measures are those which aim to minimise or cancel negative impacts likely to arise as a result of a project or plan. These measures are undertaken within the site boundary (e.g. SPA boundary) and may, for example, involve timing restrictions or changes to a projects design. Under Article 6 of the Habitats Directive, mitigation measures must be distinguished from compensatory measures. The latter are those measures designed to offset the negative or residual impacts arising from a project that may have a detrimental effect upon the site's conservation objectives.

Compensation measures may involve off-site habitat creation and/or the use of mitigation banking; a compensation mechanism which has gained popularity, particularly in the USA (Burgin, 2010, Stefanik and Mitsch, 2012, Reiss et al., 2014). In England, compensation, especially in connection

with estuaries and/or Natura 2000 sites, is commonly associated with managed realignment projects (Nunn et al., 2016), where on-site mitigation for habitat loss can be challenging. The validity of compensation habitat as a viable approach to biodiversity conservation has however been criticised as being inadequate and a mechanism for legitimising habitat destruction (Hobbs et al., 2011, Brady and Boda, 2017).

2.4.1 Mitigation habitat design and creation

The creation and provision of mitigation habitat to offset negative impacts to biodiversity is increasingly common and widespread (Gallo et al., 2017). However, the success of created habitat is variable and uptake by the desired species or aggregations will depend on many factors, including previous site use and proximity to existing available habitat (McKinstry and Anderson, 2002). Newly created wetlands are usually quickly inhabited by waterfowl (Atkinson, 2001b, Briggs et al., 2012) although this may depend on soil conditions, water quality and the availability of prey items (Gardarsson et al., 2008). Dabbling waterfowl such as Teal will be able to take advantage of any available seeds or vegetation however invertebrate prey or molluscs, favoured by some of the diving duck species, may only be present within more mature habitats (Atkinson, 2001b, Atkinson et al., 2006). As part of a flood risk management strategy, flood defences at the Humber Estuary were breached in 2003 creating a substantial area of new intertidal habitat. These areas were rapidly colonised by wildfowl though use of the site by waders was more progressive which was thought to have been a reflection of the developing invertebrate assemblage, which may take over five years to establish (Mander et al., 2007, Mander et al., 2013).

In an attempt to forecast the efficacy of proposed mitigation on the Seine estuary in France, prediction models concluded that the effectiveness of mitigation depended as much on size as quality (Durell et al., 2005). Shape may also be a significant factor; it is suggested that the most effective mitigation design is one of regular shape, the maximum practicable size with a diameter of three times the escape distance of the most sensitive species (Fox, 1997). Although this was in

respect of creating refuge habitat from recreational shooting and species sensitivities can be subjective and differ with sites, the principles remain the same.

2.4.2 Mitigation strategies for site disturbance

Where additional habitat creation is neither an option nor applicable, a number of other strategies may be used as mitigation. The most popular include the designation of disturbance-free areas and the zonation and buffering of activities (Hockin et al., 1992a, Madsen, 1995, Fernández-Juricic et al., 2005, Whitfield et al., 2008). Buffers to ameliorate the effects of disturbance are typically informed by minimum approach distances however the response given by a bird is significantly affected by species, stimulus type and previous exposure, potentially leading to underestimations being made (Glover et al., 2011, Western et al., 2012). Where there is an increase in visitor numbers and recreational activities, the use of barriers to screen wildlife from human activities has also gained momentum. This has been shown to be successful and may also be the most effective method of controlling public access and promoting habituation (Ikuta and Blumstein, 2003).

Disturbance mitigation has a role within conservation, particularly with the increase in human population, recreational activities and site development (Glover et al., 2011). However, it is fundamental that each site is assessed on its own merit and regardless of the technique or method, mitigation should be of sufficient size and quality to satisfy a range of species requirements and build resilience into the environment (Atkinson, 2001b, Durell et al., 2005).

2.5 Abberton Reservoir

2.5.1 Background and historical perspective

Abberton Reservoir is a raw water storage reservoir owned and managed by Northumbrian Water Group (NWG). Located near to the coast in Essex (Figure 2.3), it consists of three sections, the Main

(410ha), Central (49ha) and the Western (16ha). The sections are separated by two causeway embankments; the B1026 Causeway and Layer Breton Causeway.

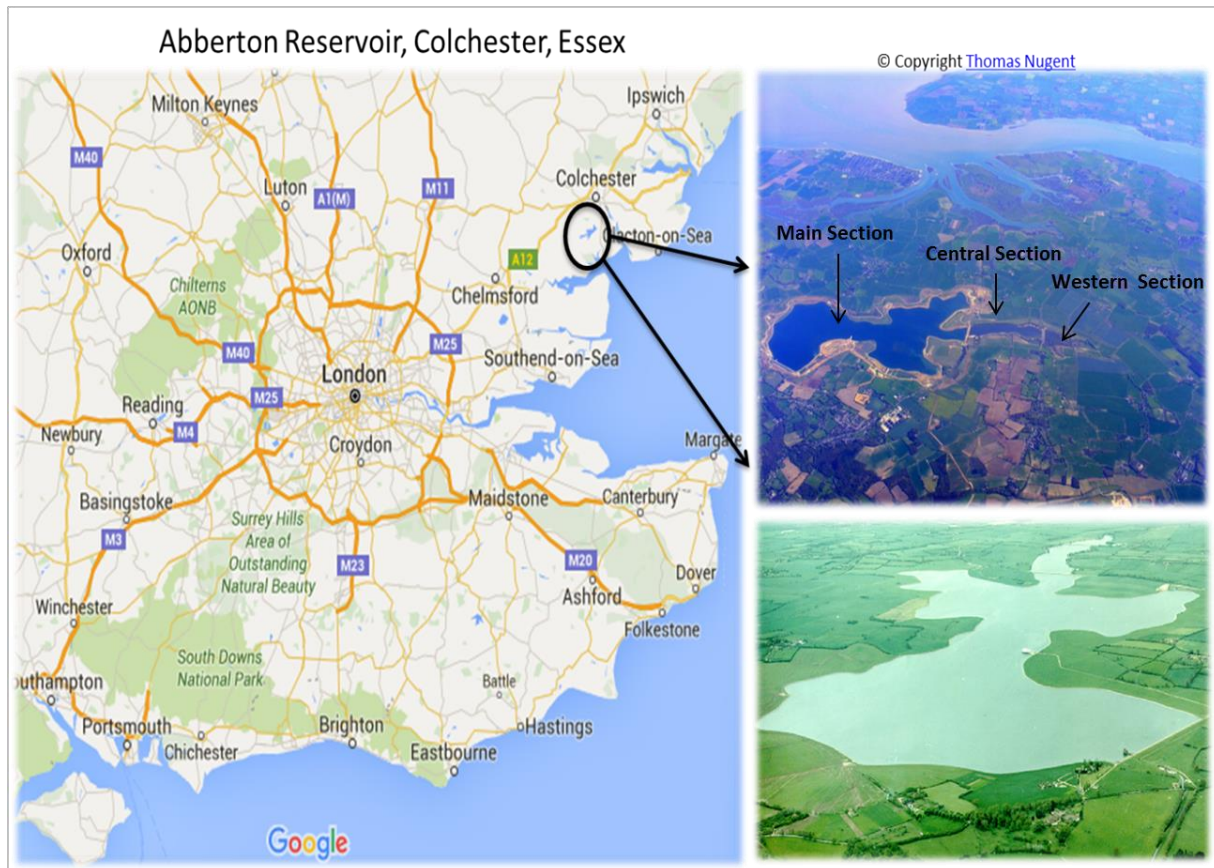


Figure 2.3: Location of Abberton Reservoir, Essex, England.

Originally constructed in the natural valley of Layer Brook by South Essex Waterworks Company in the late 1930s, 13.7km (8.5 miles) of the 17.7km (11 mile), reservoir edge were covered by a concrete edging at a slope of 1:3 which also formed the perimeter road. The reservoir was filled just prior to the Second World War and as a defence measure against invading seaplanes, 312 mines were laid across the reservoir. At the end of the war, the majority of the mines were shot and exploded however, 22 additional mines were uncovered during a particularly dry period in 1989 – 1991. During the Second World War it is reported that the RAF used Abberton Reservoir to practice low-level flying in preparation for the ‘Dam Busters’ attacks. Following the war period, demand for water continued to grow and in 1967 a project to transfer water from the Ely-Ouse River at Denver in Norfolk through rivers, pipes and tunnels into the Essex headwaters was completed. This system is

referred to as the Ely-Ouse to Essex Transfer Scheme (EOETS) and allows water to be diverted to Abberton and Hanningfield Reservoirs.

2.5.2 Abberton Reservoir waterfowl and site importance

Abberton Reservoir is one of the most important reservoirs in Britain for wintering wildfowl and acts as an important roost for waterfowl and waders feeding in the nearby estuaries. During autumn the reservoir holds important numbers of moulting waterfowl and is of significant value to migratory birds. Abberton Reservoir was designated an SPA on December 5th 1991 and updated in May 2006 following the SPA review. It qualifies under Articles 4.1 and 4.2 of the Birds Directive for the following reasons:

- Regularly supporting a nationally important breeding population of *Phalacrocorax carbo carbo* L (Cormorant), by holding 7% of the British Breeding Population (490 pairs).
- A wetland of international importance by regularly supporting, in winter, in excess of 20,000 wildfowl (39,763 wildfowl 5 year peak mean).
- By regularly supporting internationally or nationally important wintering populations of migratory wildfowl (Table 2.1).

Table 2.1: Abberton Reservoir SPA Citation Species.

Species	Species (common name)	% population
<i>Anas clypeata</i> L.	Shoveler	1.6% (North-western/Central Europe)
<i>Anas crecca</i> L.	Teal	2.5% (North-western Europe)
<i>Anas penelope</i> L.	Wigeon	0.2% (Western Siberia/North-western/North-eastern Europe)
<i>Anas strepera</i> L.	Gadwall	1.7% (North-western Europe)
<i>Aythya ferina</i> L.	Pochard	4.4% (North-western/North-eastern Europe)
<i>Aythya fuligula</i> L.	Tufted Duck	3.1% (North-western Europe)
<i>Bucephala clangula</i> L.	Goldeneye	2.7% (North-western/Central Europe)
<i>Cygnus olor</i> L.	Mute Swan	1.9% (Britain)
<i>Fulica atra</i> L.	Coot	11% (North-western Europe – wintering)

<i>Podiceps cristatus</i> L.	Great Crested Grebe	1.3% (North-western Europe – wintering)

Abberton Reservoir was also designated a Ramsar Site in July 1998 (updated in May 2006) under the Ramsar Convention and a SSSI in 1988 under Section 28 of the Wildlife and Countryside Act (1981). Further designation details including species of interest can be found in Appendix 2.1 – 2.3. This study primarily concerns the SPA species.

2.5.3 Abberton SPA species summary

The SPA species of Abberton Reservoir comprise herbivores, omnivores and piscivores and are indicative of the health and diversity of food and habitats available at the site. All species are adapted for aquatic or semi-aquatic life and have morphological features to facilitate this. The diagnostic feature that separates wildfowl from other birds is the bill which is generally flattened, broad, covered by a thin skin and tipped by a horny plate known as the ‘nail’. Dabbling ducks have spatulate bills with well-developed lamellae along the edges used for sifting food, and piscivores, have saw-like lamellae for gripping fish (Cabot, 2009). Diving ducks are able to forage upon benthic organisms such as molluscs and quite often roost in large mixed species flocks. This may result in resource competition although interspecific diving ducks vary in internal morphology, which is thought to be an adaptation to competition (Barnes and Thomas, 1987, Oka et al., 1999, Sekiya et al., 2000).

2.5.3.1 *Anas clypeata* (Shoveler)

The Shoveler is a medium-sized, heavy bodied dabbling duck designed for surface feeding and has a large spatulate shaped bill. This species often feeds through the water swinging its head back and forth to maximise the food caught in their fine curtain of lamellae (Cabot, 2009), but can also up-end and dabble in shallow water or soft mud. They are found mainly in freshwater habitats, rise easily when disturbed and are active spending much time on the wing, particularly in spring (Cramp and

Simmons, 1977). Shoveler are mostly migratory and Britain receives overwintering birds from breeding grounds in northern and eastern Europe, including the former USSR (Kirkby and Mitchell, 1993). They are omnivorous feeding on planktonic crustaceans, small molluscs, seeds, insects and larvae. However, their preferred food item is zooplankton with numbers occupying a site, linked to zooplankton density (Matsubara et al., 1994, Guillemain et al., 2000c). Whilst found on natural water bodies, Shoveler will readily use artificial wetlands and are able to adjust their site preferences in response to changing environmental conditions (Briggs et al., 2012).

2.5.3.2 *Anas crecca* (Teal)

Teal is the smallest European dabbling duck but one of the best studied through ringing projects; between Abberton Reservoir, Essex and Borough Fen, Northamptonshire, nearly 50,000 Teal have been ringed (Cabot, 2009). Teal are widespread across Britain and occupy a variety of wetland habitats although the majority occur on larger sites (Musgrove et al., 2011). They require shallow water, however they can switch to a more generalist feeding strategy and feed at a range of depths when food is abundant (Arzel and Elmberg, 2015). Teal are largely migratory and winter distribution between the Netherlands, England, Wales and Ireland is greatly dependent upon weather; cold spells cause immediate westward movement, and in severe winters they may move to France and Iberia (Cramp and Simmons, 1977). Teal are omnivorous feeding mainly feed on seeds but also on small invertebrates, larvae and molluscs. Feeding method can vary although they typically pick items of food off the water surface or filter mud through the bill in shallow water. They are known to have both diurnal and nocturnal feeding habits which largely vary with physiological condition, habitat and food availability.

2.5.3.3 *Anas penelope* (Wigeon)

Wigeon is a medium sized dabbling duck and considered one of Europe's most successful species of waterfowl. However, following the high WeBS index value that was reached in 2005/06, the number

of wintering Wigeon in Britain has declined by approximately 15%, although 2013/14 did see a slight increase compared to the previous winter (Holt et al., 2015). Wigeon are mostly found on larger wetlands sites (Musgrove et al., 2011), in close proximity to water (Mayhew, 1987), and require long undisturbed feeding periods (Mayhew, 1988). They are considered one of the shier species and are frequently observed grazing on short vegetation and on water margins in compact flocks. They predominantly feed on vegetation, preferring leaves, stems and rhizomes although they will also consume seeds and occasionally animal material (Cramp and Simmons, 1977).

Wintering Wigeon in Britain largely comprise breeding birds from Iceland, Scandinavia and Russia (Holt et al., 2015) and there is evidence to suggest the wintering distribution of Wigeon is shifting due to milder winters (Fox et al., 2016). Declines have also however been linked to changes in vegetation in breeding wetlands, specifically a decrease in habitat containing *Equisetum* (Horsetail) (Poysa et al., 2017).

2.5.3.4 *Anas strepera* (Gadwall)

Gadwall prefer fairly eutrophic, standing or slow-flowing open water with plenty of cover, dry banks and islands. They show a strong attachment to shallow water, are sensitive to human disturbance and during the flightless moulting period favour familiar sites containing shore vegetation (Gehrold, 2014). They appear less tolerant of extreme cold, wet or wind than other species of the same genus (Cramp and Simmons, 1977), although monthly WeBS indices during cold winters suggests that the UK does not receive pronounced influxes of Gadwall in response to frozen conditions on the continent (Austin et al., 2014a).

Gadwall predominantly feed on vegetative matter such as roots, leaves and seeds of pondweeds (*Potamogeton*), consumed while swimming, although they will also occasionally graze and take cereal from the land. They are largely restricted to lowland base-rich waters with a strong growth of submerged macrophytes (Fox and Salmon, 1989), and when conditions allow the development of a

rich macrophyte flora, are more likely to be found on gravel pits than reservoirs (Briggs et al., 2012). Gadwall have been observed kleptoparasitising from Coot (LeSchack and Hepp, 1995, Austin et al., 2014b), particularly when food abundance declines in late winter (McKnight and Hepp, 1998).

2.5.3.5 *Aythya ferina* (Pochard)

Pochard is a medium sized diving duck with a high crown, sloping forehead and long bill. They are predominantly bottom feeders, normally diving to depths of 1 - 2.5m and require uncluttered, open water, prolific in submerged plant and animal food (Cramp and Simmons, 1977). They are mainly migratory, although there are some resident and breeding birds in Britain and tend to occur in larger groups than Tufted Duck during the nonbreeding period (Fox and King, 2011). In 2013/14, the WeBS index for Pochard dropped to its lowest ever point, indicating that the UK's wintering population has halved in under 20 years (Holt et al., 2015). Population declines in this species have been attributed to a shift away from western wintering areas such as the UK (Austin et al., 2014a). Indeed, mild winters are known to reduce distances of within-winter movements by Pochard (Keller et al., 2009).

The Pochard is omnivorous feeding on both plant and animal material which varies with season and locality. Food is mainly obtained through diving and includes seeds, rhizomes, tubers and leaves. The most frequently recorded aquatic plants consumed include pondweeds (*Potamogeton*), stonewort's (*Chara*), milfoil (*Myriophyllum*), hornworts (*Ceratophyllum*) and sedges (*Carex*). Animal material includes crustaceans, molluscs, annelids, insects, larvae and some amphibians and small fish (Cramp and Simmons, 1977)

2.5.3.6 *Aythya fuligula* (Tufted Duck)

The Tufted Duck is a common species and distributed more widely than most other wildfowl (Musgrove et al., 2011). They are a compact diving duck capable of sustained diving to depths of 3 - 14m which enables deeper, more open water bodies to be used (Cramp and Simmons, 1977). They are predominantly migratory and omnivorous obtaining food from the benthos by diving - although

they will occasional up-end or feed from the water surface. There appears to be considerable variation in diet according to locality, year and season, depending on availability and abundance of food (Cramp and Simmons, 1977). At wintering locations they prefer to feed on animal materials favouring molluscs, crustaceans and insects although seeds may form a major part of the diet (Cramp and Simmons, 1977). Many studies link Tufted Duck to Zebra mussels (*Dreissena polymorpha*); a favoured prey item which they catch during dives up to 5m then swallow whole and crush in the gizzard (Leeuw et al., 1999, Werner et al., 2005, Van Nes et al., 2008).

2.5.3.7 *Bucephala clangula* (Goldeneye)

Goldeneye is a medium sized, stocky diving bird with capabilities of turning over stones on the bottom at depths up to 8m (Cramp and Simmons, 1977). They occur on larger waterbodies and at coastal sites (Musgrove et al., 2011), although on passage will make use of most water bodies including standing, flowing, natural or artificial. Numbers of Goldeneye in the UK have declined sharply since the 1990's although the rate of decrease has slowed and is thought to be linked to cold winters in western Europe (Austin et al., 2014a). They primarily feed on molluscs, crustaceans, and insect larvae (Cramp and Simmons, 1977), with chironomid larvae forming the most dominant part of the diet (Winfield and Winfield, 1994, Stewart and Lauder, 1997).

2.5.3.8 *Cygnus olor* (Mute Swan)

The Mute Swan has the most southerly breeding range of the Eurasian swans and has seven recognised populations; two discrete populations being those in Britain and Ireland which are largely sedentary (Rowell and Spray, 2004). The Mute Swan is a large bird that forms strong pair-bonds, matures slowly and have a prolonged family life (Cramp and Simmons, 1977). Non-breeding individuals form mobile groups while breeding pairs maintain a territory and can display territorial behaviour towards other waterbirds (Gayet et al., 2010).

They prefer rivers, canals, streams, gravel pits and reservoirs and are gregarious herbivores in autumn and winter (Gayet et al., 2010). Due to their large size they can consume substantial amounts of vegetation with evidence suggesting that the distribution of *Potamogeton perfoliatus* (an abundant macrophyte species at Abberton Reservoir), is limited to areas where the pressure of swan grazing is low (Sandsten and Klaassen, 2008). Feeding is predominantly obtained from water up to 1m in depth and they will also feed on emergent plants and seeds by grazing and dabbling on the water's edge and on grasses, crops and herbs when on land (Cramp and Simmons, 1977, Wood et al., 2012).

2.5.3.9 *Fulica atra* (Coot)

Coot wintering in the UK comprise resident and immigrant birds from other regions of north-west Europe; part of a large overall population that includes an estimated 180,000 in Britain (Austin et al., 2014a). They are wide ranging and predominantly inhabit large, still or flowing water bodies. Coot nest in dispersed pairs and can produce several broods a year (Severcan and Yamaç, 2010), but are largely gregarious with flocks of several thousand forming during the winter period. They are omnivorous although diet primarily consists of vegetative matter from aquatic plants as well as their seeds. They will also consume grasses, cereal crops and animal matter including aquatic invertebrates and molluscs, although not to the same extent as Tufted Duck and Pochard (Werner et al., 2005). Feeding method typically involves diving then consumption at the surface leading to other species such as Gadwall stealing their food (kleptoparasitism), although it is not thought numbers of Coot directly influence site selection by Gadwall (Briggs et al., 2012).

2.5.3.10 *Phalacrocorax carbo carbo* (Cormorant)

These are large, hooked billed marine and fresh water piscivores that can form large breeding colonies on extensive inland waters. Cormorant winter both on the coast and inland and it is thought

two separate populations are involved; the coastal breeding *carbo* and the continental *sinensis* which in eastern England, is more prevalent inland (Musgrove et al., 2011).

Cormorant avoid widespread floating vegetation or obstructive emergent growth and spend long periods on exposed and slightly elevated positions to dry, oil and preen (Cramp and Simmons, 1977). They feed almost entirely on fish obtained from diving from the surface using their large webbed feet for underwater propulsion and are known to form tight coordinated hunting groups, a method referred to as flock-fishing (Kallander, 2008). In the past they were locally domesticated for aiding fishermen, however in recent times they have been persecuted, particularly by inland fisheries out of concern for a reduction or damage to fish stock.

2.5.3.11 *Podiceps cristatus* (Great Crested Grebe)

The Great Crested Grebe is a large piscivorous grebe with a long neck and dagger-like bill. They winter inland and on the coast where they can form large off-shore flocks (Cramp and Simmons, 1977, Musgrove et al., 2011), although WeBS counts show that the UK's winter population of Great Crested Grebe has declined by 25% in the last decade (Austin et al., 2014a). During the breeding season they can be found on fairly shallow lakes, gravel pits and reservoirs (Cramp and Simmons, 1977), with the egg laying period typically running from the end of March until the end of May (Cheriet et al., 2015). They prefer ample, but not too dense emergent aquatic vegetation, especially fringing with some submerged bottom cover and limited floating material (Cramp and Simmons, 1977). On large water bodies they prefer shallow sheltered bays where they dive for food; chiefly fish, although aquatic invertebrates are also consumed.

2.6 Abberton Reservoir Enhancement Scheme

2.6.1 Rationale behind the Abberton Reservoir Enhancement Scheme

NWG supplies drinking water to approximately 1.8 million people in Essex, north Suffolk and south Norfolk. NWG has a statutory duty under the Water Industry Act 1991 to provide all its customers with a sufficient supply of potable water and to do so in such a way as to conserve and enhance the environment. In the early 1990s, water resource planning predicted demand for water would rise by approximately 6% over the following 25 years (Hill, 2007). In order to meet this predicted increase in water demand, the Abberton Scheme was proposed. The Abberton Scheme comprises three main elements:

1. Abberton Reservoir Enhancement (increased water storage capacity by enlargement of the existing reservoir).
2. Denver Licence Variation (change in abstraction timing and volume).
3. Transfer Enhancement (construction of two new water transfer pipelines).

The focus of this study is on the Abberton Reservoir Enhancement component (hereafter the Abberton Scheme). The Abberton Scheme primarily involved increasing the storage capacity by 58%; achieved by raising the main dam level by approximately 3m to 22.7m above ordnance datum. When the raised water level was achieved, the footprint of the reservoir increased in volume by approximately 40%. The Abberton Scheme in its entirety (all three components) was one of the largest planning applications in UK history. Planning permission was granted in April 2009 following submission of the ES and Study to Inform an Appropriate Assessment (STIAA). Construction started in 2010 and was completed in 2013.

2.6.2 Summary of construction activity associated with the Abberton Scheme

Major construction activities comprising the development and enlargement of Abberton Reservoir are summarised in Figure 2.4. Further details can be found in Appendix 2.4.



Figure 2.4: Illustrated summary of the main construction activities associated with the Abberton Scheme.

2.6.3 Summary of ecological enhancements associated with the Abberton Scheme

From the outset and in addition to engineering objectives, the Abberton Scheme was designed to avoid adversely affecting the SPA site integrity and to deliver ecological enhancements. Specific enhancement activities relating to the SPA features (the waterfowl) were largely a result of an extensive longitudinal study carried out as part of the EIA process. These activities are outlined in Section 2.7 and further discussed and analysed in Chapter 6. Major activities comprising the enhancement element are summarised in Figure 2.5.

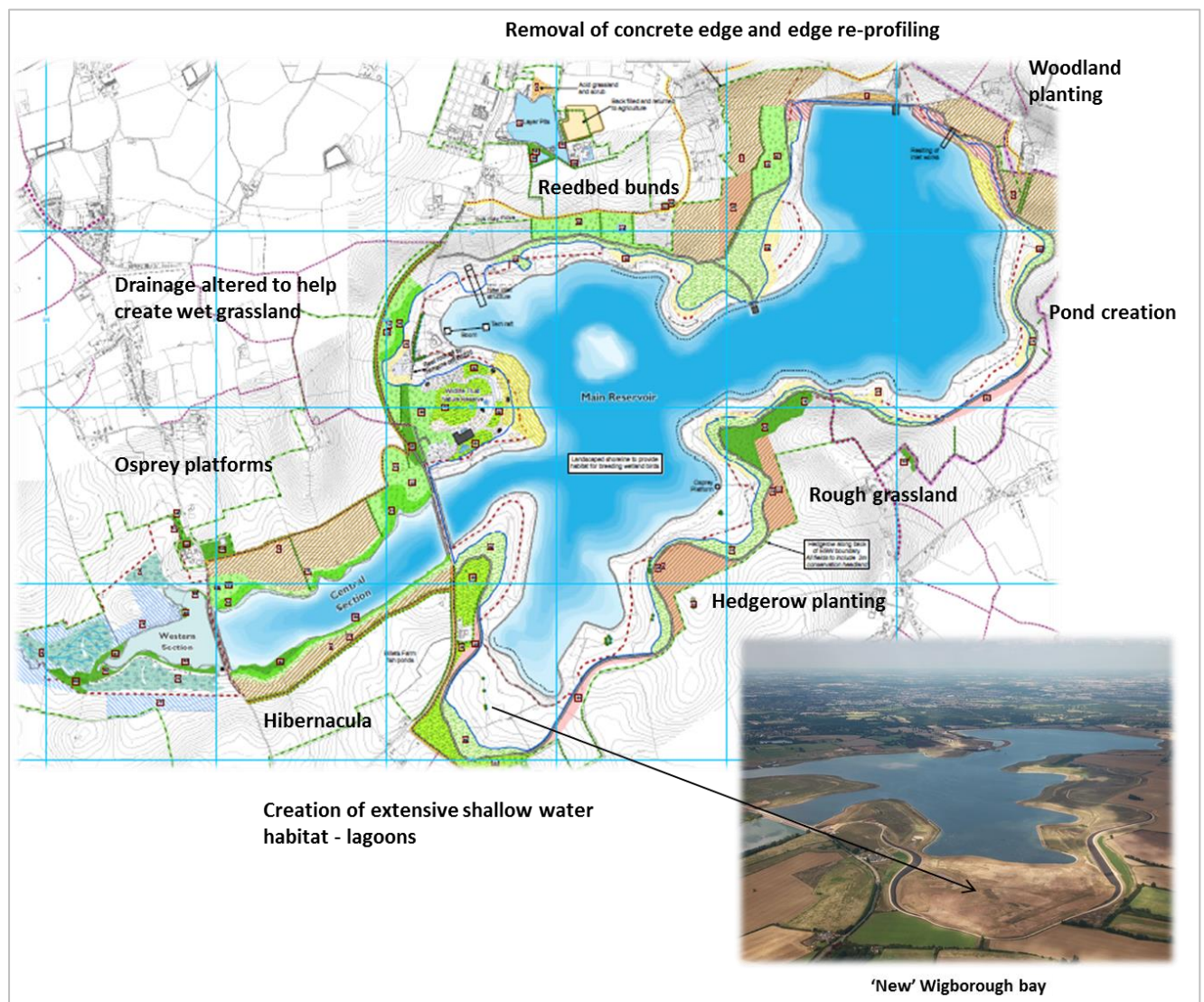


Figure 2.5: Summary of the main ecological enhancements incorporated into the Abberton Scheme.

2.7 STIAA recommendations, mitigation measures and impact predictions

2.7.1 Assessment of the Abberton Schemes impacts and enhanced reservoir design upon Abberton Reservoir waterfowl

The Abberton Reservoir Study to Inform the Appropriate Assessment (STIAA) was carried out in respect of proposals to enhance Abberton Reservoir. Its primary aim was to assess the effects of the proposal on the integrity of waterfowl populations in order to comply with Regulation 48 of the Habitats Regulations in relation to the sites conservation objectives. Long term trend data spanning 1969 to 2008, together with baseline assessment work undertaken between 2004 and 2008, were used to investigate the effect of drawdown on Abberton Reservoir waterfowl and to inform the enhanced reservoir design. Survey data included waterfowl abundance and distribution during the moulting, winter, diurnal and nocturnal periods. Data were used to assess the potential effects arising from construction of the enhanced reservoir and under the proposed water level regime. The objectives of the study were to:

- Collate and assess existing ornithological data;
- Investigate the effects of past drawdown events;
- Present updated survey data for waterfowl in order to assess effects of the Abberton Scheme;
- Ensure that there would not be an adverse effect on the integrity of the SPA site.

Analysis showed that the reservoir becomes particularly important during the low water levels in August to October, after demands on supply of the summer months expose the shallow areas. These shallow areas, particularly those at a depth of 0-1m were shown to be important for the dabbling ducks, principally Gadwall, Shoveler and Teal. As a consequence, one of the key considerations of

the Abberton Scheme and the new design was to maximise the extent of available 0-1m depth habitat to the dabbling waterfowl. To achieve this, and to provide additional benefits, the new reservoir design ensured that the enhanced reservoir would maintain existing reservoir performance or was improved under the predicted demand profiles calculated by NWG's Water Resources team. Investigating the historical survey data revealed that numbers of waterfowl using Abberton Reservoir are at their lowest during the summer months i.e. the importance of the reservoir is primarily overwinter, reflected by its conservation designations. Waterfowl populations also fluctuate across the years with numbers (for Teal in this instance), varying by up to 86% (Hill, 2007). A number of factors accounted for this including the effect of water drawdown, weather and surrounding habitat.

As a result of analysis and to further enhance the reservoir for waterfowl, a range of habitat enhancement measures were proposed. These were incorporated into the Abberton Scheme's design and included:

- The creation of shallow sloping shorelines on the Main Reservoir, providing 194ha of new shoreline and 16.7km of shoreline at top water level (an increase in 2km from the existing reservoir), including 37ha of bunded shallow lagoon areas;
- Aquatic vegetation enhancement and management in the enhanced reservoir;
- Habitat creation including establishment of wet grassland, ditches and lagoons at the Western Section of the Reservoir;
- Water level management in the Central Section to maximise the amount of 0-1m habitat available for waterfowl in conjunction with drawdown conditions in the Main Section;
- The planting of food crops in the newly created shorelines, which upon flooding will release substantial quantities of seed food for dabbling waterfowl;
- Fish population manipulation as appropriate to reduce competition with waterfowl for macrophytes and invertebrate food;

- Providing opportunities for enjoyment and learning including extended bridleways and footpaths.

2.7.2 Impact prediction and mitigation measures

Mitigation requirements and impact predictions for the Abberton Scheme were outlined in the STIAA. The study used the engineering objectives of the Abberton Scheme together with the sites conservation objectives to help inform the design and programme of the construction works to minimise disturbance impacts to waterfowl. The nature of potential disturbance resulting from construction activity was considered to result primarily from visual sources i.e. movement of the construction team on the shoreline and from noise generated from activities such as concrete breaking and sheet piling. Due to the sites importance over winter, those activities considered most disturbing were programmed to occur outside of this time period i.e. in the summer months. This was based on spatial distribution analysis of waterfowl, habitat changes and noise data from experimental construction events. Through careful programming and phased works, the STIAA determined there would be no adverse effects during construction upon the SPA and as such, did not require any additional mitigation habitat creation. Any potential residual impacts were addressed by the creation of approximately 6ha of shallow wetland habitat at the Western Section of the reservoir (4ha was determined by the STIAA to be sufficient as displacement habitat). Any birds displaced as a result of construction work on the Main Section could then relocate to the Western Section and still be within the site boundary. For the purpose of this study, the displacement habitat created at the Western Section is termed the Abberton Reservoir mitigation habitat and is assessed in Chapter 6.

Chapter 3

General methods

3.1 Data collection and organisation

3.1.1 Study species

Abberton Reservoir has 11 species listed as SPA special features (Chapter 2: Section 2.5.2); this study focuses on nine of those species (Table 3.1). Excluded species are the Cormorant (*Phalacrocorax carbo carbo*) and Goldeneye (*Bucephala clangula*). The Cormorant is excluded due to differences in use of the reservoir and in its biology compared to the other species and Goldeneye, because this species is only present at Abberton Reservoir for a few months of every year (typically December through to March).

Table 3.1: Study species consisting of nine Abberton SPA waterfowl species.

Common name	Species (L)	Feeding guild
Gadwall (GA)	<i>Anas strepera</i>	Dabbler
Shoveler (SV)	<i>Anas clypeata</i>	Dabbler
Teal (T)	<i>Anas crecca</i>	Dabbler
Wigeon (WN)	<i>Anas penelope</i>	Dabbler/grazer
Coot (CO)	<i>Fulica atra</i>	Diver
Tufted Duck (TU)	<i>Aythya fuligula</i>	Diver
Pochard (PO)	<i>Aythya ferina</i>	Diver
Mute Swan (MS)	<i>Cygnus olor</i>	Grazer
Great Crested Grebe (GG)	<i>Podiceps cristatus</i>	Piscivore

3.1.2 Waterfowl data

Waterfowl populations at Abberton Reservoir have been monitored since 1969 as part of the British Trust for Ornithology (BTO) Wetland Bird Survey (WeBS) which aims to identify trends and changes in the distribution of non-breeding waterbirds in the UK. In addition, since 2004, monthly surveys were undertaken in order to assess and predict the impacts arising from construction of the Abberton Scheme. For each monthly survey, which was standardised to occur in the middle of each month, all SPA waterfowl were counted across the reservoir complex using binoculars, telescopes and recorded using the BTO species code system on a handheld Trimble Nomad personal digital

device (PDA). For consistency, accuracy and replication, overall responsibility for ornithological data collection was held by Darren Frost with specific responsibility for the Western Section data collection, the authors. Count methodology was adapted from a standard point count survey as described in Bird Census Techniques (Bibby et al., 1992). To enable quantitative assessment of waterfowl distributions, to reduce count duplication during surveys and for consistency with WeBS count methodology, the reservoir was split between sections using defining boundaries or prominent points along the reservoir perimeter (Figure 3.1). Using bespoke data capture software designed for Abberton Reservoir waterfowl surveys (Frost and Frost, 2004), each waterfowl occurrence was geographically referenced (X and Y coordinates) and placed within the centre of a coded 100m² grid (Refgrid) system (Figure 3.2). Using this methodology, numbers of each waterfowl species were recorded in the Refgrid cell (978 in total) associated with that particular area of Abberton Reservoir. The software enabled individual observations (point data) and aggregations of waterfowl (rafts) to be recorded. Where rafts of birds covered a large spatial area (and therefore many Refgrid cells), the software split the total number of birds between the total number of cells e.g. a raft of 1,568 birds located across 800m² would be recorded as 196 birds in eight Refgrid cells. Compatibility of the software with Excel allowed data to then be exported and loaded into a geographical information system (GIS) for further analysis.

The monitoring of highly mobile species over a large spatial extent can be difficult and estimates should be reliable and repeatable from year to year (Bibby et al., 1992). To increase accuracy of waterfowl count data at Abberton Reservoir, the same skilled observers and vantage points were used throughout the study period. Additionally, observers were familiar with the site and used marked locations as reference points to assist in distance measurements.

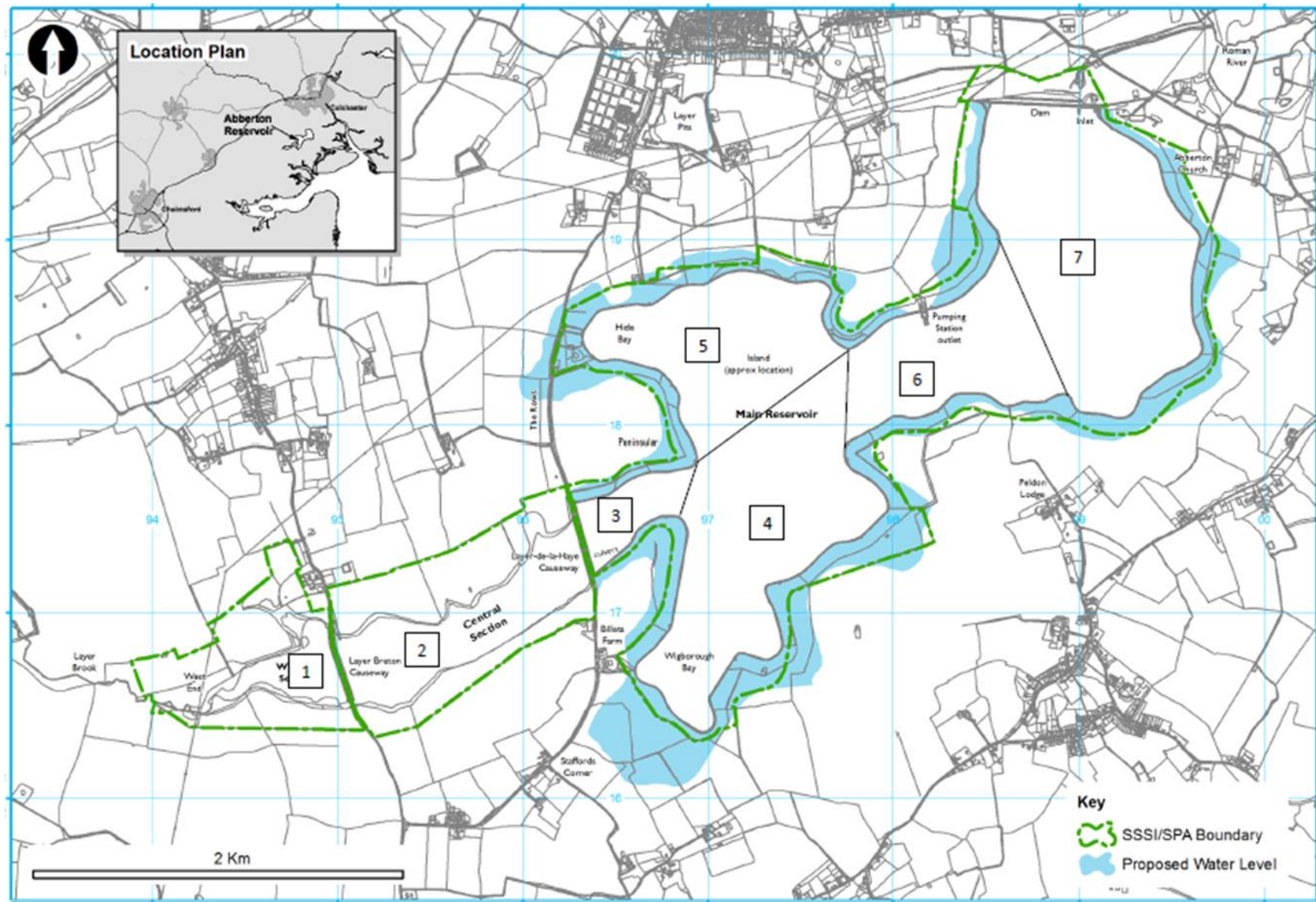


Figure 3.1: Sectional split of Abberton Reservoir for monthly waterfowl surveys and taken from the Abberton Reservoir migratory waterfowl survey report (Frost, 2005).

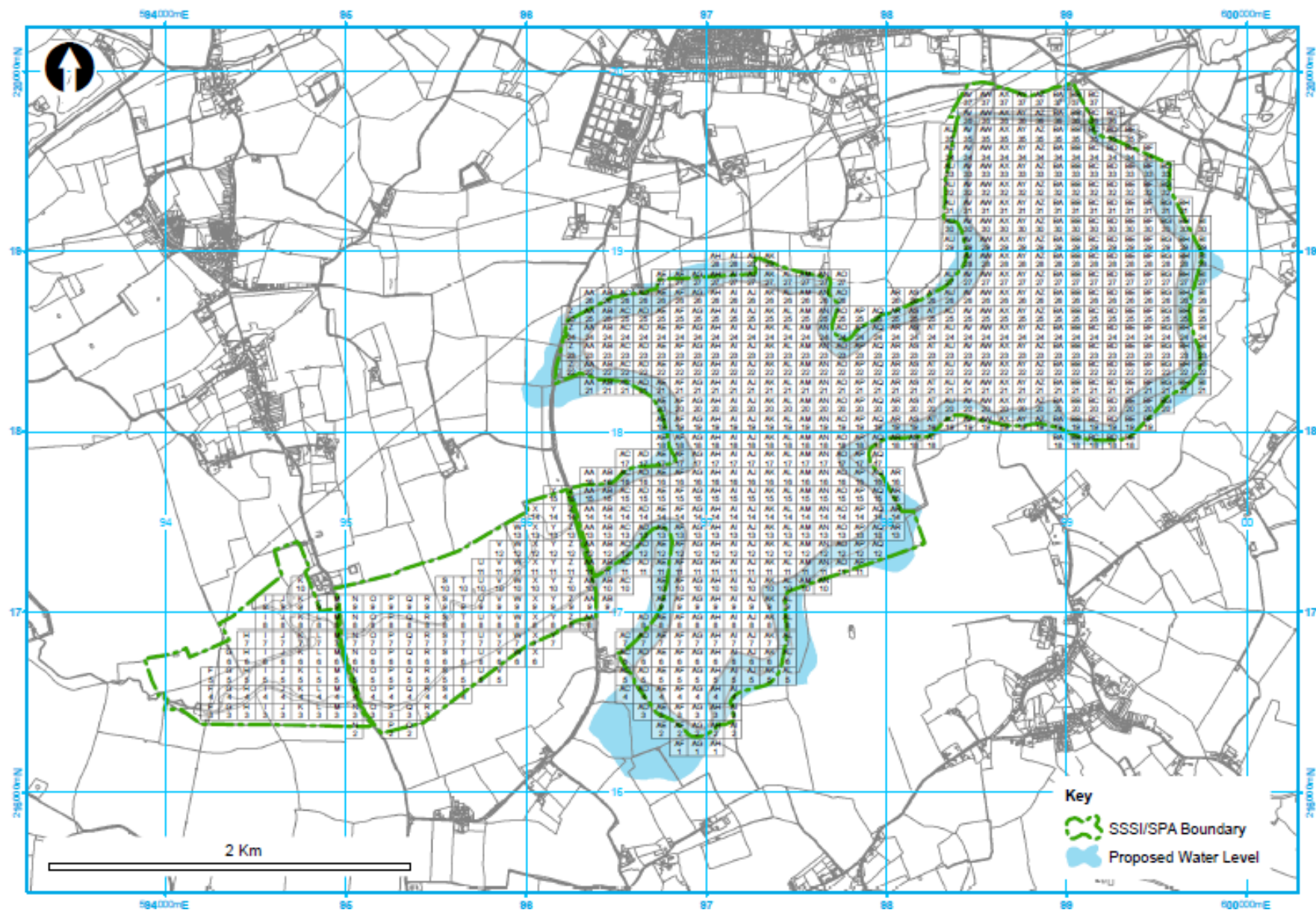


Figure 3.2: 100m² survey grid (798 cells in total) used for Abberton Reservoir waterfowl surveys. Taken from Abberton Reservoir migratory waterfowl survey report (Frost, 2005).

3.1.3 Environmental variables

3.1.3.1 Water level data

Water level measurements at Abberton Reservoir were taken at weekly intervals from the Water Resource team (ESW) as part of an operational process to monitor levels within Abberton Reservoir. Readings were taken for the Main and Central Section throughout the study period. Prior to 2011, the Main and Central Sections were hydrologically connected and all samples were taken from the offtake pumping station using an automated Siemens ultra-sonic level detector. During 2011 – 2013, additional readings for the Central Section were taken from B0126 causeway by the principle construction contractor Carillion. Water level data obtained closest to the waterfowl survey count date were used in conjunction with bathymetric survey data to calculate the average water depth for each 100m² Refgrid cell. Water depth is expressed and calculated as above ordnance datum (AOD) with land dominated cells i.e. those with >75% dry land, excluded. This was partly due to a lack of water depth (bathymetric) information and because some cells contained other habitat types e.g. woodland. For visual mapping purposes, interpolation functions within the spatial analysis tools in Esri ArcMap 10 were used to create digital elevation models (DEM). Smooth splines illustrating water depth were then created using a mask of the reservoir boundary within the raster analysis settings, with the processing extent set to the reservoir boundary. Due to the lack of bathymetric data within the deeper portions of the reservoir (the middle), depth values for these areas could not be calculated; therefore for the purpose of this research these areas are assigned a value of >4m.

3.1.3.2 Distance to shoreline

Distance to shoreline was calculated in ArcMap 10 as the minimum distance (m) from the central point of each 100m² cell to the shoreline i.e. from the centroid of each cell, in order to standardise calculations. This allowed for the fact that the waterfowl data captured on the PDA device automatically places the bird count within the centre of the 100m² Refgrid cell.

3.1.3.3 Macrophyte cover

A key feature of Abberton Reservoir is its abundant submerged aquatic vegetation community which provides a valuable food source for waterfowl, either directly, or by providing food and shelter for invertebrates (O'Hare et al., 2007, Deak et al., 2008, Russell et al., 2009, Hansson et al., 2010, Patra et al., 2010, Gayet et al., 2011). The species diversity and relative abundance of aquatic vegetation at Abberton Reservoir was recorded annually (typically in July) throughout the survey period (2006 – 2013). Surveys involved experienced divers snorkelling perpendicular from the shoreline along 21 predetermined 100m transects. Using bathymetric survey data, high resolution aerial photography (from July 2011) and Esri ArcMap 10 functions, submerged vegetation was estimated as a percentage cover (%) for each 100m² Refgrid cell across the reservoir. A ground-truthing exercise comparing % cover estimates with macrophyte survey results was also undertaken to further validate calculations. The % cover of submerged vegetation was included as a variable in construction and mitigation habitat analysis (Chapters 5 and 6).

3.1.3.4 Weather data

Weather information i.e. wind speed, temperature and rainfall data were obtained via the Colchester Weather Site (<http://www.tijou.co.uk/weather/>) located 11.2km (7 miles) from Abberton Reservoir. Information was collected using a LaCrosse WS 2500 weather station with a PC interface based in Colchester, Essex. Sensors are solar powered and communicate to the base station by radio transmission with a WS 2500-25 temperature and WS 2500-16 rain gauge processed through WsWin software. Wind speed was measured in kilometre per hour (km/h), temperature in degree Celsius (°C) and rainfall in millimetres (mm). Weather variables were used in the construction disturbance assessment (Chapter 5).

3.1.4 Construction disturbance

3.1.4.1 Data collection

Data spanning four years (2010 – 2013) were collected and assessed in order to quantify and map the extent of disturbance during the construction phase of the Abberton Scheme. Data collection was carried out throughout the four year construction period by the author as part of the Ecological Clerk of Works role. Location and extent of disturbance occurring each day of the monthly waterfowl count were obtained through examination of:

- Weekly contractor programmes (see Appendix 3 for an example);
- Monthly work programmes (Appendix 3), including earthwork and structures (building of operational structures) meeting minutes;
- Contractor daily work allocation sheets;
- Email correspondence between engineers, project and earthwork managers and the Ecological Clerk of Works (the author). This was mainly used to confirm timings and to record any deviations from the programme;
- Site diaries.

3.1.4.2 Data collation and disturbance magnitude calculations

Construction activity data were compiled for each day of the waterfowl survey and for each 100m² Refgrid cell, the level of construction activity assessed and categorised as having high (1), medium (2) or low level (3) disturbance. The concept of setting disturbance categories based on various construction activities was adapted from studies investigating the effects of construction works on estuarine birds at Saltend, Humber Estuary (Cutts et al., 2009). The disturbance value assigned to each Refgrid cell was based on the following attributes:

- Number of machines working in each Refgrid cell.

- Number of people working in each Refgrid cell.
- Distance of that disturbance event to the shoreline (split into distance bands where <100m from the shoreline = band 5, <200m = band 4, <300m = band 3, <400 = band 2 and <500m = band 1).

Each Refgrid was then further split into total disturbance (T), machine disturbance (M) and people disturbance (P) using only the machine or people attributes as appropriate. Calculations were:

Total disturbance (T) = number of foot operatives x person disturbance band + total machines x machine disturbance band + distance band.

Machine only disturbance (M) = number of machines x machine disturbance band + distance band.

People only disturbance (P) = number of foot operatives x person disturbance band + distance band.

Category and magnitude of disturbance data were then loaded into ArcMap 10 and combined to produce attribute layers for each month/day during the construction period. For visual purposes and to assist in distance related disturbance assessment, 100m buffer zones were created around each 'disturbed' Refgrid cell. To reflect magnitude of disturbance for that portion of the reservoir, each buffer zone was colour coded and labelled; e.g. total disturbance category 1 (high impact) was shown in red and labelled as DTC1. Construction data were then combined with species distributional data, an example of which is shown in Figure 3.3.

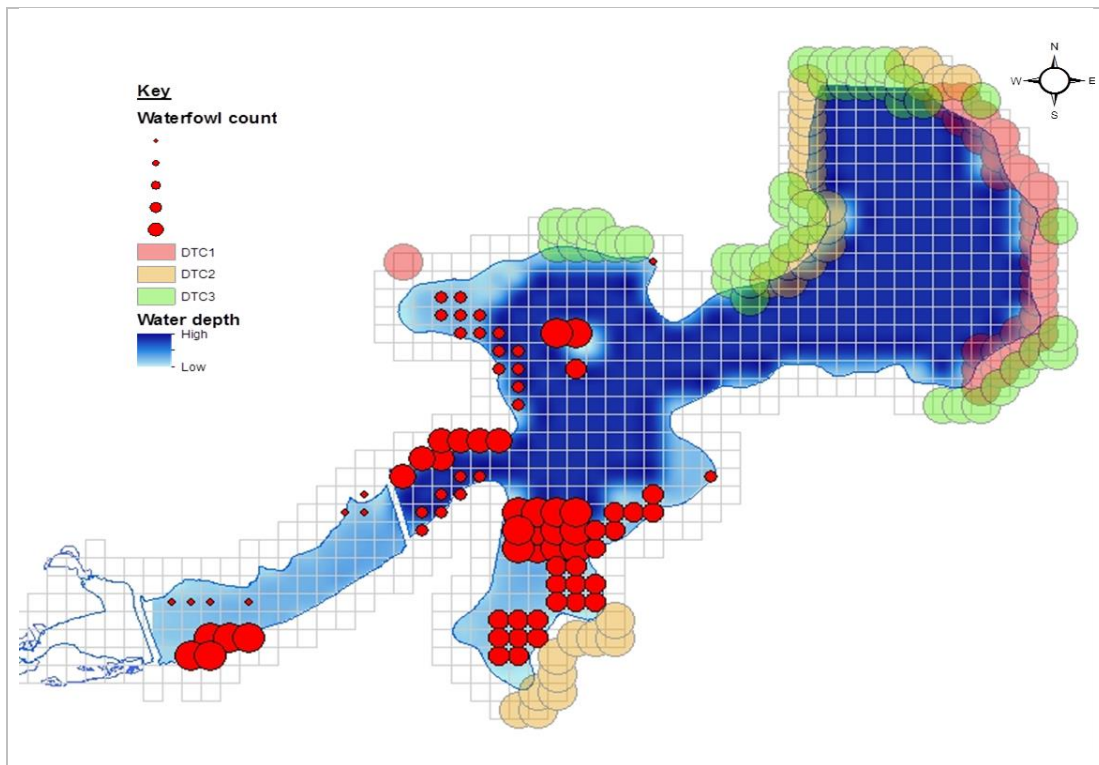


Figure 3.3: Example of construction category mapping showing Teal distribution, water level (DEM) and construction disturbance (total disturbance) using data from September 2010.

3.1.4.3 Construction disturbance – distance calculations

To extract the distance of each waterfowl occurrence to the nearest source of disturbance (in each disturbance category), 'Near' in Proximity (analyst tools) in ArcMap 10 was used. This adds two attributes 'Near_FID' (feature identify) and 'Near_Dist' (distance) and determines the distance from each feature in the input features to the nearest feature in the near features, within the search radius (none specified). The calculated FID can then be matched with the corresponding Refgrid cell to give the distance of waterfowl to the nearest construction event within that category. The distance of each waterfowl occurrence to disturbance was included alongside environmental and disturbance related covariates in construction disturbance assessment. For covariate assessment see Chapter 5: Section 5.2.2.3 and for statistical methodology refer to Section 3.2 below.

3.2 Statistical analysis

All statistical analyses were carried out using the open source computer programme R (version 3.3.2) using the R interface R Studio (R Core, 2015).

Monitoring mobile species over large spatial extents is a challenging yet fundamental aspect of ecology and conservation. Population monitoring can be problematic, not least because assessments are usually based on count data which have many properties that present difficulties in statistical validation (Fowler and Cohen, 1996, Hoef and Boveng, 2007, Zeileis et al., 2008). In addition, individual species may show high inter-month count variance which is particularly evident at overwintering waterfowl sites such as Abberton Reservoir, due to highly fluctuating counts across the winter period. Due to the nature of waterfowl data used in this study, a range of statistical methods were employed including non-parametric and parametric analyses in conjunction with spatial analytical tools.

3.2.1 Kruskal-Wallis and *post hoc* Nemenyi test

Kruskal-Wallis is a non-parametric test for comparing medians of three or more samples and was used to assess annual variation and differences in SPA waterfowl aggregations (aggregated data for the nine species) across the eight years. The test is commonly employed and performed on ranked data, where observations are converted to their ranks within the overall data set (Heath, 2003, Bargagliotti and Greenwell, 2015). Whilst the test does not assume data are normally distributed (which can be checked through the use of Q-Q plots, histograms and the Shapiro-Wilk test), it does require homogeneity of variance (homoscedasticity or equal variances). Homogeneity was tested using Levene's test which is accessed within the Lawstat package. For combined SPA species analysis, where the Kruskal-Wallis test indicated statistical significance, the *post hoc* pairwise Tukey and Kramer (Nemenyi) test in the PMCMR package was applied to locate the source of significance (Liu and Chen, 2012).

3.2.2 Mann-Whitney U-test

The Mann-Whitney U or Mann-Whitney-Wilcoxon test is a non-parametric test used to compare differences between two independent groups. It is a comparison of the averages of samples where the values of observations are converted to ranks (Fowler and Cohen, 1996). Similarly to other non-parametric tests, it does not assume data are normally distributed but does assume that samples are random and that the distribution is symmetrical around the mean. It tests whether the population distributions are identical and was used to determine significant differences in species count data for years during construction compared to years pre-construction and to test for differences in species use of the Western Section following displacement habitat creation.

3.2.3 Generalized linear modelling

An important statistical development over the last 30 years has been the advance in regression analysis provided by Generalized linear models (GLMs) (Guisan et al., 2002). GLMs are mathematical extensions of the general linear model and can be used to quantify the relationship between a dependent variable and several independent (explanatory) variables, including mixtures of categorical and continuous variables. Part of their success is due to their ability to deal with ecological data that typically do not fit the standard normal distribution and/or where the variance is not constant (Zeileis et al., 2008). GLMs have three important properties; the error structure, the linear predictor and the link function. It is the link function that allows expansion and generalization of the linear model.

GLMs were used to investigate the influence of predictor variables on species use of the Western Section in years prior to and during construction (Chapter 6). Variables included in model analysis were year, month, species count, macrophyte cover and distance to shoreline. Analysis for years during construction included a variable representing the total disturbance level for the survey day. GLMs with a negative binomial distribution were applied for eight of the nine species with the

exception being Great Crested Grebe for which a quasi-poisson distribution was used (due to under-dispersion). An overview of data exploration, model selection and model validation for GLM analysis is provided in Figure 3.4.

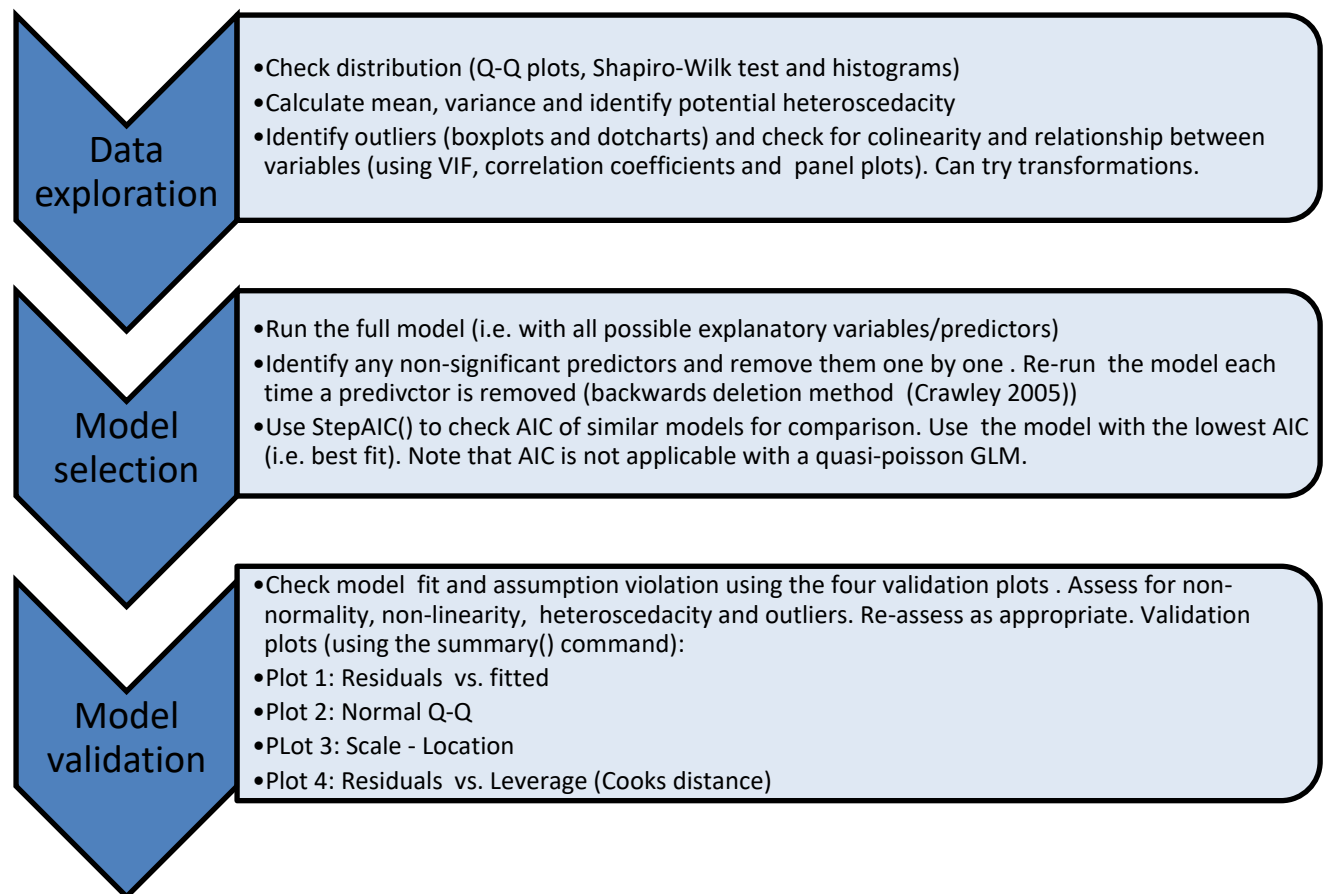


Figure 3.4: Process of data exploration, model selection and model validation for GLM analysis.

3.2.4 Hurdle model analysis

GLMs with a quasi-poisson or negative binomial error distribution are appropriate for many data issues however, they are not sufficient for modelling excess zeros which are frequently encountered within ecology. Whilst the recording of a zero count may be of ecological interest, their inclusion presents analytical difficulties, particularly in determining predictor variables associated with species abundance (Linder and Lawler, 2012). Models to account for excess zeros are usually split between mixture and two-part Hurdle models (Cragg, 1971). Both include a logistic regression for the zeros in the data and a count regression (either Poisson or Negative binomial distribution). However, they

each take different approaches in dealing with the zeros. Hurdle models consist of two components; a truncated count component is employed for positive counts and a hurdle component (Figure 3.5) models the probability that a zero is observed (Zeileis et al., 2008). In a Hurdle model, all zero observations are considered true zeros and they have been used successfully within the literature e.g. (Linder and Lawler, 2012, Savage et al., 2015, Balderama et al., 2016, Lyashevskaya et al., 2016, Neelon et al., 2016, Baetschmann and Winkelmann, 2017). Because the zeros encountered during waterfowl counts at Abberton Reservoir are ‘true zeros’ and reflect the absence of a species, they were of interest and included in analysis. Hurdle models also allow the inclusion of many predictor variables including numerical, categorical and any associated interaction terms. Due to the ability to analyse zero and positive counts against numerous predictor variables (separating the two in the statistical output), Hurdle model analysis was identified as the most appropriate statistical technique for construction disturbance analysis (Chapter 5).

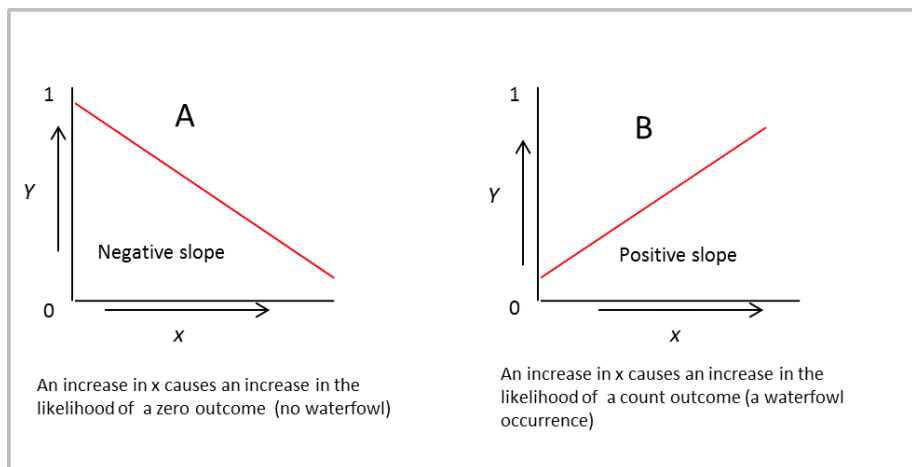


Figure 3.5: Authors interpretation and explanation of the binomial (binary outcome) component of the Hurdle model process which models the probability of a zero observation. A negative relationship is illustrated in A and the interpretation for a positive relationship in B.

Although many zeros are considered true counts, they can also arise as a result of structural or survey error, therefore zero counts relating to Refgrid cells with land coverage were considered false negatives and excluded from analyses. All other zeros were retained as they were deemed of ecological interest. The minimum adequate model (MAM) was achieved by first running a full Hurdle model (using hurdle in the pscl package (Jackman, 2012)) with all possible predictors (after

the data exploration (Figure 3.4)), with the highest non-significant term excluded one by one (step-wise regression method). Each time a term was excluded the model was re-fitted and the goodness of fit/model complexity assessed using Akaike Information Criterion (AIC) in the Faraway package (Faraway, 2016). Competing models, removal of, and the inclusion of interaction terms were also assessed using the `lrtest` command in the `lmtest` package (Zeileis, 2002). `lrtest` assists in determining the best fitting model by comparing the log likelihood of two competing models. If the difference is statistically significant, the model containing more variables is deemed a better fit. `lrtest` is applicable for nested model comparison and since the count regression model is nested within the Hurdle model, use of `lrtest` was appropriate.

Assessment of model fit followed recommendations outlined by Zuur (Zuur et al., 2009, Zuur et al., 2010) and consisted of plotting model residuals against fitted values, and residuals against each explanatory variable used in the model and Q-Q plots. Additionally, Hurdle models for each species were compared with several other models identified as suitable for these analyses including GLMs with both a negative binomial (NB GLM), Poisson (P GLM) and quasi-poisson (QP GLM) distribution. The NB GLM provided an adequate fit with outputs similar to the count component of the Hurdle model. However, the Hurdle model was considered more suitable for these analyses due to the nature of the zeros, which were excluded in the GLM models.

3.3 Spatial statistics and mapping

3.3.1 Multi-Distance Spatial Cluster Analysis (Ripley's K Function)

Species distributional or trait data based on a range map (extent-of-occurrence) often display spatial autocorrelation, i.e. locations close to each other exhibit more similar values than those further apart (Dormann et al., 2007). Ripley's K Function is multi-distance spatial cluster method that summarises spatial dependence and illustrates how the spatial clustering (spatial autocorrelation) or dispersal of features change with varying neighbourhood sizes. By analysing the K Function, the

distributional behaviours of spatial point data can be effectively monitored (Huang et al., 2017), and it can be determined if data are clustered or randomly distributed. Analysis is undertaken for a range of distances with the peak difference between observed and K values (the DiffK value) demonstrating where spatial processes are most pronounced. When the observed K value at a particular distance is larger than the expected, the data are more clustered than random; when the K value is smaller than expected, the distribution is more dispersed than random.

Ripley's K Function in ArcMap 10 was used to determine if the Abberton Reservoir species data exhibited statistically significant clustering or dispersion and to identify the distance at which it was most prominent. The distance associated with the largest difference (DiffK) determined the most appropriate distance band for cluster and outlier analysis (Anselin Local Moran's I: Chapter 4). When specified, the weight field represents the number of incidents (and locations remain fixed) therefore the weight field was set to each species count. This ensures that only the weighted values are randomly distributed and are evaluated for clustering. To correct for any undercount bias for features located near the survey extent boundary, simulate outer boundary values was applied (it corrects for underestimates in points close to the boundary by mirroring those within the boundary). To maintain consistency with Refgrid sizes, distance increments of 100m (starting at 0) were used (Figure 3.6).

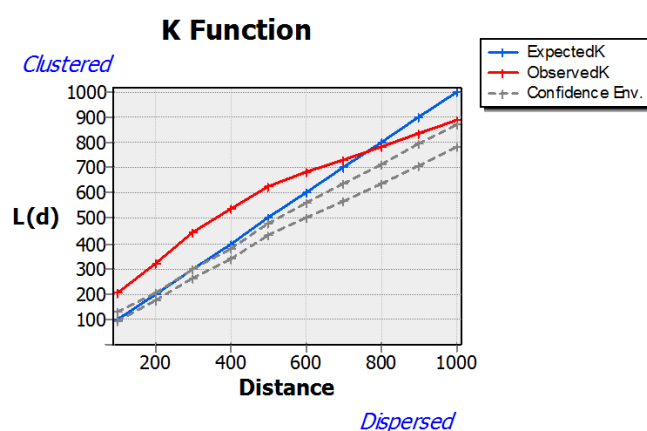


Figure 3.6: Example of Ripley's K Function output using Abberton waterfowl data for April – September 2006. In this instance, the DiffK value was greatest at a distance of 300m.

3.3.2 Cluster and outlier analysis (Anselin Local Moran's I)

Anselin Local Moran's I is a spatial mapping tool used to identify and visualise locations of statistically significant hotspots, coldspots and outliers given a set of weighted features. It is a measure of spatial autocorrelation that uses the Anselin Local Moran's statistic to test for clustering in which the slope of the regression line corresponds to Moran's I and significance is based on a permutation test (Anselin et al., 2006). It calculates a Moran's I value, Z-score, a *p*-value and a code to represent the cluster type (COType). The Z-score and *p*-value are measures of statistical significance which are set at the 95% confidence level and the COType distinguishes between a statistically significant cluster of high values (HH); cluster of low values (LL); an outlier in which a high value is surrounded by low values (HL) and an outlier in which a low value is surrounded by high values (LH).

Anselin Local Moran's I was used to visualise and compare differences in temporal clustering for and between each analysed SPA species (Chapter 4). The relationship between each data point (here considered neighbours) was specified through the conceptualisation of spatial relationships parameter which for these analyses was set to Zone of Indifference. This allows every feature to be considered a neighbour of every other feature without imposing sharp boundaries and was used in conjunction with a specified distance band/threshold distance. Results of Ripley's K Function (above) determined the most appropriate distance band; set to the distance (m) at which each species exhibited maximum clustering.

3.3.3 Spatial autocorrelation (Moran's I)

Moran's I was used to further analyse the extent of observed spatial autocorrelation in Abberton Reservoir waterfowl and to assess any changes in spatial pattern relating to construction activity (Chapter 5). Monthly data were evaluated as exhibiting a clustered, dispersed or random pattern based on feature locations and attribute values using the Global Moran's I statistic. Output statistics

are detailed in a report published as a PDF with a positive Moran's score indicating a tendency towards clustering and a negative score, a tendency towards dispersal. For consistency with other spatial analyses, the conceptualization of relationship was defined as Zone of Indifference with the distance threshold set at 100m (Euclidean distance). An example output of highly significant clustered data (for Coot in September 2013) is shown in Figure 3.7.

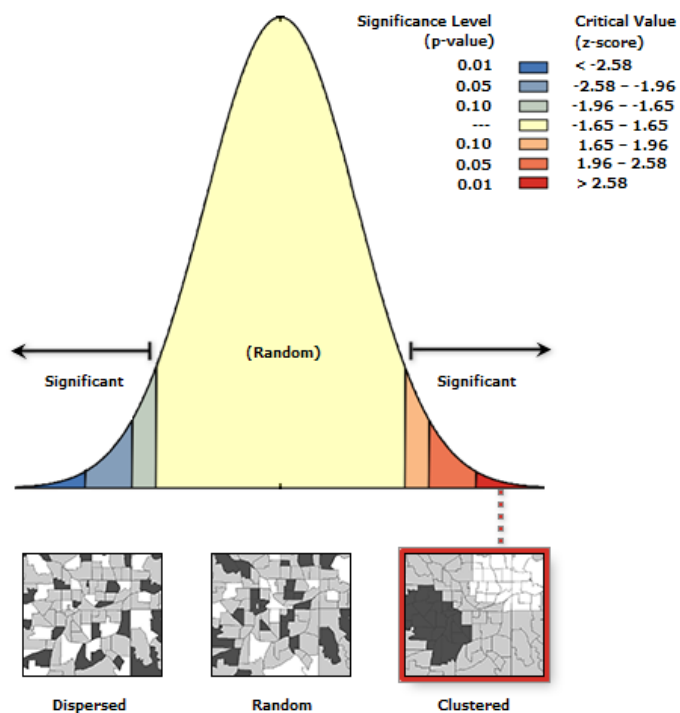


Figure 3.7: Output of Moran's I measure of spatial autocorrelation using Coot (September 2013) as an example. Data are assessed as being significantly clustered.

3.3.4 Kernel density estimation (KDE)

In conjunction with spatially joined distribution data, the Kernel density estimation tool in ArcMap 10 was used to assist in assessment of the created mitigation habitat at the Western Section of Abberton Reservoir (Chapter 6). Kernel density estimation (KDE) is a non-parametric statistical technique that calculates the density of features across a given area using a probability density function and is useful in approximating patterns of distribution frequently found in ecological data (O'Brien et al., 2012).

Kernel Density Estimators are essentially a generalisation on histograms; the simplest non-parametric density estimator. Histograms divide data values into bins whereas KDE removes the dependence of the end points and bin width to create a continuous smooth curved surface over each data point. The search radius (bandwidth) determines the extent of the smoothing parameter and for point data is fixed to circular. Only points that fall within the set neighbourhood are calculated and density remains highest at the location of the point, decreasing with increasing distance. KDE is a particularly useful and popular approach because of its non-parametric flexibility with ecological point data which does not typically fit the standard distribution.

Chapter 4

Abberton Reservoir waterfowl distribution 2006 - 2013

4.1 Introduction and aims

Abberton Reservoir consists of three sections, the Main, Central and Western, totalling approximately 480ha. The reservoir is internationally important for waterfowl and is designated a Ramsar site, Special Protection Area (SPA) and Site of Special Scientific Interest (SSSI). Due to a predicted increase in demand and lack of available water within Essex, Abberton Reservoir was extended through the Abberton Scheme, an enlargement project designed primarily to increase the reservoir's water storage capacity. Construction occurred during the year period 2010 through to 2013 and the assessment of the effects of construction activity on the SPA waterfowl populations is the subject of this study. In order to accurately assess any significant effects, waterfowl distribution in the absence of construction disturbance must also be determined. The four years prior to construction activity (2006 through to 2009), provides a baseline enabling comparison between the two study periods (pre-construction and during construction), and ultimately assists in determining the effect of construction activity on Abberton Reservoir SPA waterfowl. Analyses presented in this chapter consider the Abberton SPA aggregations as an assemblage i.e. total numbers across the site, differences in use of the three sections and provides an assessment of spatial distributional patterns for nine individual Abberton SPA species.

The aims of this chapter are to:

- Describe trends in Abberton Reservoir waterfowl distribution patterns, both as an SPA aggregation and for selected species, in the four years prior to construction of the Abberton Scheme (2006 – 2009) and the four years during construction (2010 – 2013).
- Compare and contrast spatio-temporal waterfowl distribution patterns (SPA aggregations and selected species) between the two study periods (prior to and during construction).

4.2. Methods

4.2.1 Data collection

Waterfowl data for the nine Abberton Reservoir SPA species (Chapter 3: Methods) were obtained from monthly waterfowl surveys carried out by Darren Frost and Kim Wallis across the study period as part of the Abberton Reservoir waterfowl population monitoring. Waterfowl distribution patterns were calculated by overlaying a 100m² grid (Refgrid) over the reservoir, then utilising software and mapping functions to position each waterfowl occurrence within the corresponding coded 100m² cell (Figure 4.1 provides an example and Methods: Section 3.1.2, further details). Data were then input into a count database and loaded into a geographical information system (Esri ArcMap 10) enabling species assemblages as well as individual species to be mapped and analysed.

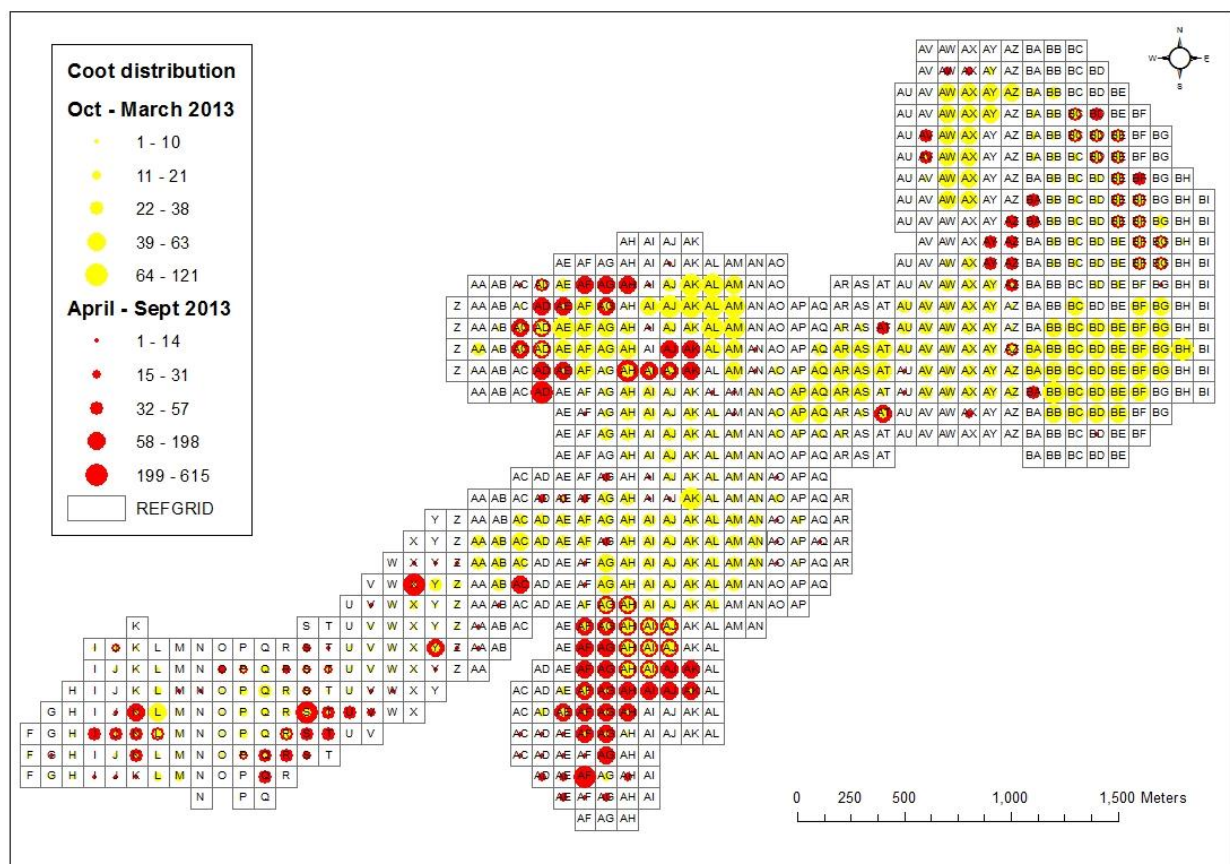


Figure 4.1: Abberton Reservoir waterfowl distribution and 100m² survey grid cells (using Coot during 2013 as an example).

4.2.3 Data analysis – SPA waterfowl aggregations

Data analysis was carried out using the R software package (version 3.2.2) and included counts for the nine SPA species combined; representing the SPA waterfowl assemblage. For individual species analyses refer to Section 4.2.4 and for additional information on analytical methods, Chapter 3.

Most parametric tests require that the underlying data are normally distributed and make strict assumptions which may not always hold true (Fowler and Cohen, 1996). Shapiro-Wilk, a commonly used test for normality and Levene's test within the Lawstat package, were used as data exploration tools and to assist in determining the most appropriate statistical analyses for these data. The Kruskal-Wallis test is a non-parametric test where observations are converted to their ranks in the overall data set. The *post hoc* pairwise comparison using Tukey and Kramer (also referred to as Nemenyi) test in the PMCMR package was applied where the Kruskal Wallis test indicated significance.

The Mann-Whitney U-test or Mann-Whitney-Wilcoxon test is also a non-parametric test used to compare medians within samples. Similar to the Kruskal-Wallis, it is based upon rank values and was used to determine differences between waterfowl during construction compared with pre-construction. Figure 4.2 shows the method of data exploration and statistical analysis.

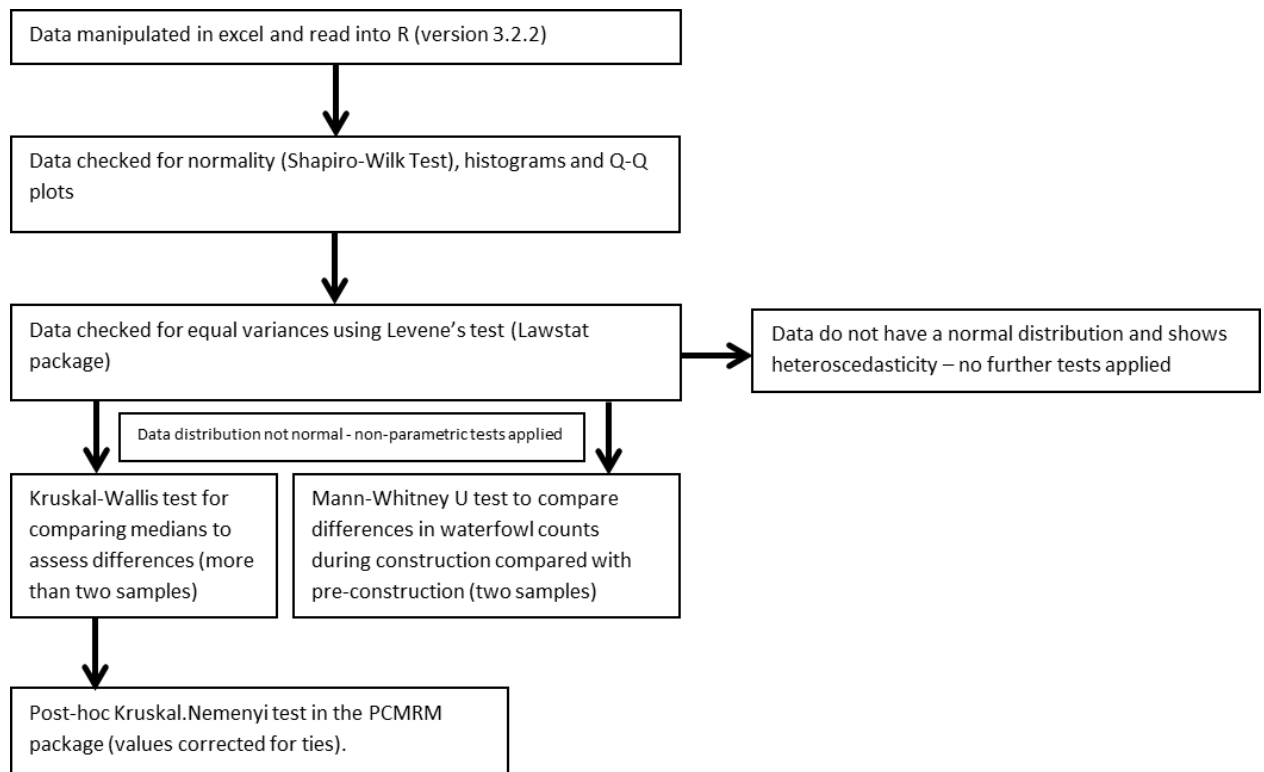


Figure 4.2: Method of data exploration and statistical analysis.

4.2.4 SPA species analysis

4.2.4.1 Aggregation (join-count) of species count data

Species count data were aggregated into two temporal groups representing spring/summer (April – September) and autumn/winter (October – March). The spring/summer months represent the collective months where construction activity occurred (see Chapter 2: Section 2.7.2), providing a baseline for disturbance assessment (Chapter 5). In addition, aggregating waterfowl count data allows inclusion and assessment of months where species counts are low, and would otherwise be excluded from these analyses. Refer to Chapter 3 for the data capture and organisation process.

4.2.4.2 Cluster analysis

Ripley's K Function in Esri ArcGIS 10 was used to investigate spatial dependence in Abberton waterfowl (SPA) aggregations and species. This method determines whether features exhibit

statistically significant clustering at multiple scales or over a range of distances. The distance associated with the largest difference between observed and expected values is the distance at which clustering is most pronounced and was used to inform the distance band for further cluster analysis (Anselin Global Moran's I).

Anselin Local Moran's I is a spatial mapping tool used to identify and visualise locations of statistically significant hotspots, coldspots and spatial outliers using the Anselin Local Moran's statistic. It is a measure of spatial autocorrelation that calculates a Moran's I value, a z-value, a *p*-value and produces a code to represent cluster type. The code (COType) distinguishes between a statistically significant cluster of high values (HH), a cluster of low values (LL), an outlier surrounded by high values (HL) and an outlier surrounded by low values (HL). The z-score and *p*-score are measures of statistical significance and the calculated Moran's I value indicates whether data are exhibiting spatial clustering or dispersion. For additional information on spatial statistics methods refer to Chapter 3: Section 3.3.

4.2.4.3 Determining species differences between pre and during construction

To determine statistically significant differences between species distribution during construction compared with pre-construction, data exploration followed the methods outlined in Figure 4.2. The Mann-Whitney U test was used to determine any significant differences in species use of each section (Main, Central and Western) between the two survey periods.

4.3 Results

4.3.1 Use of Abberton Reservoir by SPA waterfowl aggregations – an overview

4.3.1.1 Pre-construction (2006 – 2009)

Abberton Reservoir is primarily important for waterfowl during the moulting and overwintering period with high numbers from August through to January and peaking during September and October (Figure 4.3). Combined SPA waterfowl counts were highest in the four years pre-construction during September and October 2008 with numbers reaching 24,033 and 33,591 respectively. Levene's test revealed equal variance between the pre-construction years i.e. waterfowl distribution between the years were similar and observed differences across the years were non-significant (Kruskal-Wallis test).

4.3.1.2 During construction (2010 – 2013)

SPA waterfowl during the construction phase (2010 – 2013) followed the same annual cycle as observed during years pre-construction with counts highest during the winter period (Figure 4.4).

Peak counts were observed in autumn/winter of 2011 with numbers reaching 28,019 in October. Equal variance in total waterfowl counts across the years during construction was achieved and any observed differences non-significant. A comparison of total SPA waterfowl counts for years pre-construction compared with during construction was also non-significant (Mann-Whitney U-test).

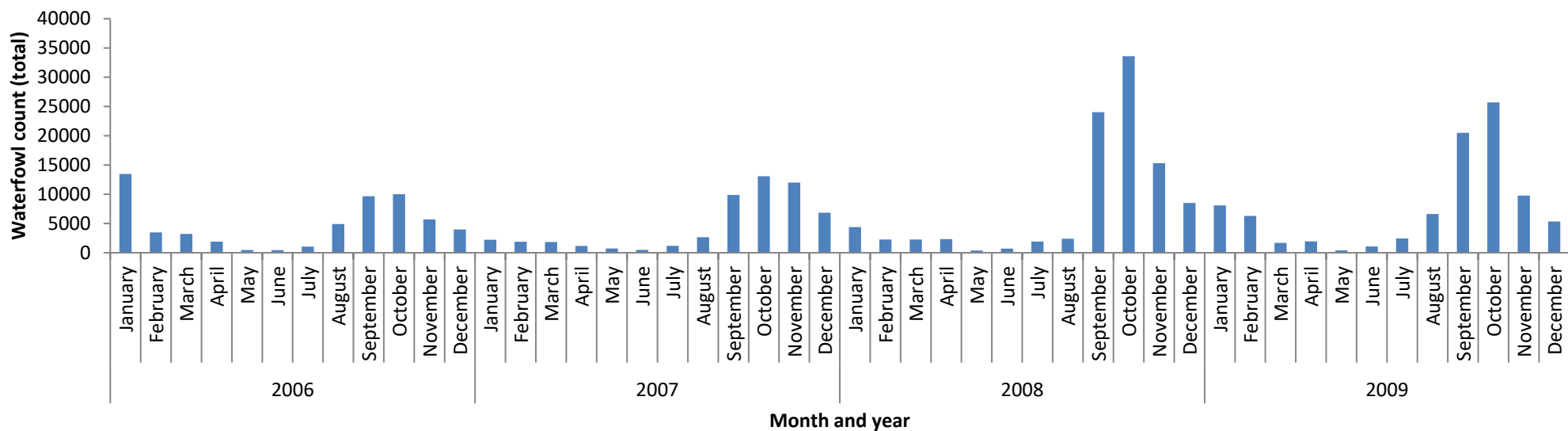


Figure 4.3: Total number of Abberton Reservoir waterfowl (GA, SV, T, WN, CO, TU, PO, MS & GG) over the four year pre-construction period 2006 – 2009. Peak counts typically reached in October.

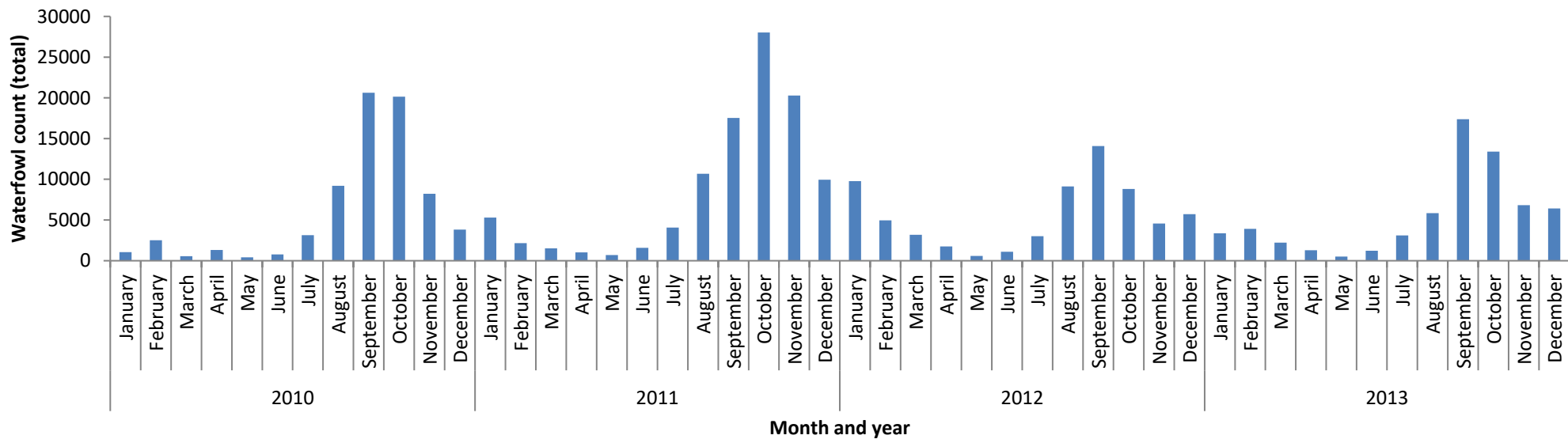


Figure 4.4: Total number of Abberton Reservoir waterfowl (GA, SV, T, WN, CO, TU, PO, MS & GG) over the four year construction period 2010 – 2013. Peak counts typically reached in September.

4.3.2 Use of Abberton Reservoir by SPA waterfowl aggregations – section and month

4.3.2.1 Pre-construction (2006 – 2009)

The Main Section represents the largest extent of available aquatic habitat (Table 4.2) and attracts the highest total numbers of waterfowl (Figure 4.5); particularly during the autumn and winter period when waterfowl numbers peak (see Appendix 4.2). The Central Section, totalling 49ha generally supported the highest number of waterfowl during the months of August and December when low water levels expose the shorelines. Despite high numbers of waterfowl (total count for all sections), observed in autumn/winter of 2007/2008, the difference was not significant in comparison with the other pre-construction years.

Table 4.2: Percentage of Abberton Reservoir represented by each section (Main, Central and Western).

Section	Size (Ha)	% of reservoir
Main	410	86.3
Central	49	10.3
Western	16	3.4

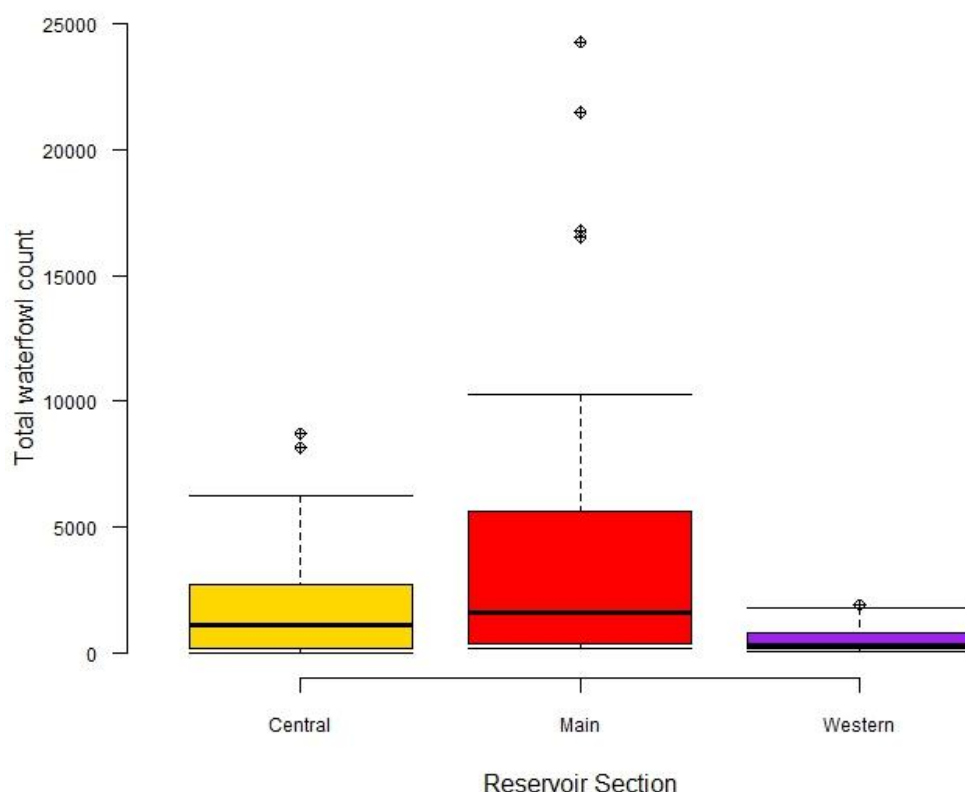


Figure 4.5: Waterfowl use across the three sections of Abberton Reservoir in years pre-construction.

A comparison of total waterfowl use for each section throughout the pre-construction period (2006-2009) was non-significant. However, when waterfowl were analysed for each month with respect to section occupancy, Kruskal-Wallis tests revealed differences across the years within the Main Section for January $X^2(3) = 8.2106$, $p = 0.04$ and within the Western Section for February $X^2(3) = 8.9767$, $p = 0.02$ and December $X^2(3) = 9.4139$, $p = 0.02$. A *post-hoc* test using Tukey and Kramer indicated that for February, there were differences between years 2006 and 2009 although care must be taken when interpreting this result due to a significant Levene's test (unequal variances were observed).

4.3.2.2 During construction (2010 – 2013)

In keeping with years 2006 -2009, the Main Section attracted the highest number of waterfowl during construction (Figure 4.6) and numbers increased in comparison with years pre-construction. The median values (all SPA species combined) pre-construction and during construction were 56 and

113.5 respectively. The difference between the two was significant (Mann Whitney U₈₀₆₉₉, n = 432 p = 0.001).

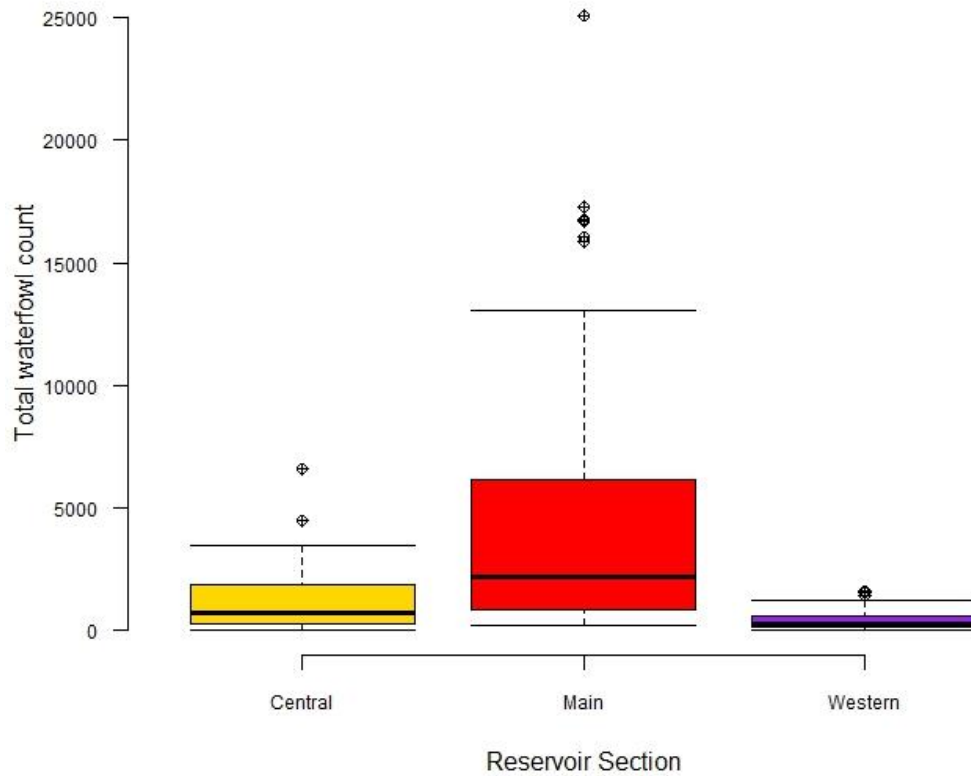


Figure 4.6: Waterfowl use across the three sections of Abberton Reservoir in years during-construction.

When all sections were considered to represent Abberton Reservoir as a total, a Kruskal Wallis test revealed a significant effect of year on March SPA waterfowl counts ($\chi^2(3) = 9.0043$, $p = 0.02$ with the *post hoc* test indicating that these differences were between years 2010 and 2012. When SPA waterfowl counts were analysed with respect to each section and month, significant differences were observed in the Central Section for the months of January, March, September and December and in the Western Section for March, August, September and December (Table 4.3). The only significant difference in SPA waterfowl counts for the Main Section was observed for March.

Table 4.3: Summary of results for month/section analysis (for all SPA species) during construction. Highlighted results indicate statistical significance (see bottom of Table).

Month	Section	Equal variance assumed (Levene test)	Kruskal-Wallis test		Post hoc test (corrected for ties)
			χ^2 value	p-value	
January	Main	Yes	Not significant		N/A
	Central	Yes	7.7244	0.05	2010/2012
	Western	Yes	Non-significant		N/A
February	Non-significant				
March	Main	Yes	7.6399	0.05	Non-significant
	Central	No	N/A	N/A	N/A
	Western	Yes	8.4258	0.03	Non-significant
April	Non-significant				
May	Non-significant				
June	Non-significant				
July	Non-significant				
August	Main	Yes	Non-significant		N/A
	Central	Yes	Non-significant		N/A
	Western	No	7.5363	0.05	N/A
September	Main	Yes	Non-significant		N/A
	Central	No	16.172	0.00	2010/2011 and 2010/2013
	Western	Yes	10.272	0.01	2011/2013
October	Non-significant				
November	Non-significant				
December	Main	Yes	Non-significant		N/A
	Central	Yes	12.895	0.00	2010/2011 and 2010/2013
	Western	No	11.418	0.00	2010/2011

Significant test result

Caution in interpretation due to significant Levene test result (can be robust to minor deviations)

4.3.3 Use of Abberton Reservoir by SPA waterfowl aggregations – species analyses

4.3.3.1 Distribution of Gadwall pre-construction

Over the four years prior to construction activity there was spatial autocorrelation in the distribution of Gadwall indicating this species was not distributed across the reservoir in a random manner but that Gadwall numbers in adjacent cells were more similar than would be predicted by chance. In all four years (2006 - 2009), the largest proportion of Abberton Reservoir (all three sections combined and across 797 100m² cells), was classified as having non-significant clustering (Anselin Local Moran's I index). Ripley's K-Function, used to identify where clustering is most pronounced, assessed Gadwall distribution across the reservoir and identified that spatial dependence between clusters was most pronounced at distances of 300m and 500m.

Map outputs of Anselin Local Moran's I cluster and outlier analysis have been combined with Gadwall distribution across Abberton Reservoir (Figure 4.7). Gadwall are classified as a dabbling duck species (Cramp and Simmons, 1977, Gehrold et al., 2014), and for the months of April – September, the most significant clustering was observed for the Western Section. Within the Main Section, they were predominantly situated around the edges of the reservoir although non-significant cluster aggregations were also present to the north-west (namely Hide Bay) and south west (Wigborough Bay) areas.

During the months October through to March, 2006 and 2009 were similar with significant high clusters of Gadwall within all three sections. 2007 and 2008 were also similar with significant high clusters predominantly located within the Central Section. For these months and for all years, the data indicate that the Western Section was less important for Gadwall compared with the summer period.

4.3.3.2 Distribution of Gadwall during construction

Over the four years during construction activity, Gadwall displayed spatial autocorrelation with the largest proportion of Abberton Reservoir classified as having non-significant clustering. With the exception of October – March 2011, the distance between each Gadwall cluster was most pronounced at 200m and 300m. For a summary of cluster analysis (Anselin Local Moran's and Ripley's K-Function) pre and during construction for all species see Appendix 4.3.

Gadwall distribution and outputs of Anselin Local Moran's I cluster and outlier analysis for the years during construction are shown in Figure 4.8. During April through to September, significant clustering was observed within all three sections, with aggregations particularly low during 2013 in comparison to the other years (2010 – 2012).

Aside from significant high clusters within the north-west corner by the main dam in years 2010 and 2012, the distribution pattern of Gadwall using the Main Section for the months October through to March was more random. Similar to the pre-construction period, Gadwall used the Central Section throughout the year with the Western Section generally less occupied during the winter period.

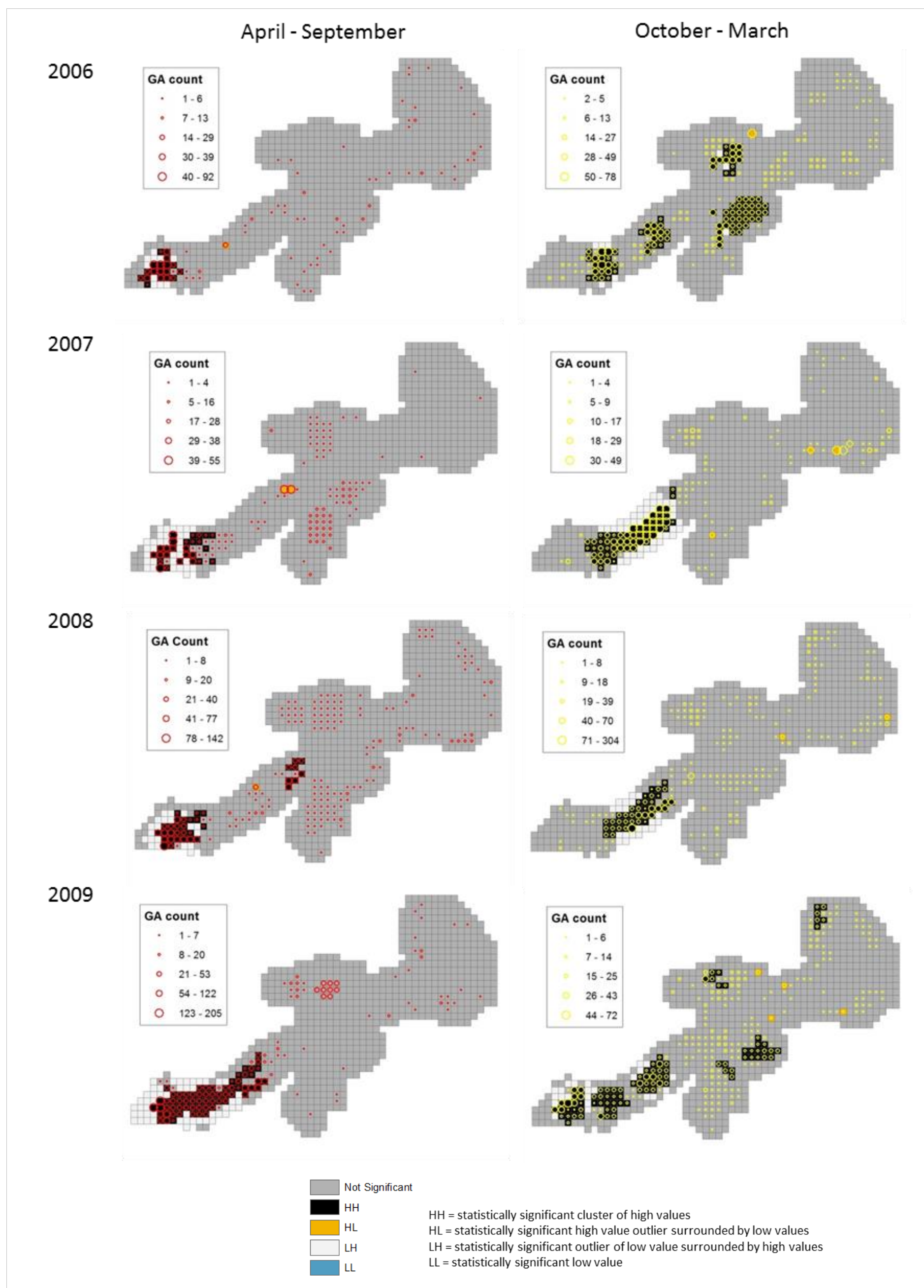
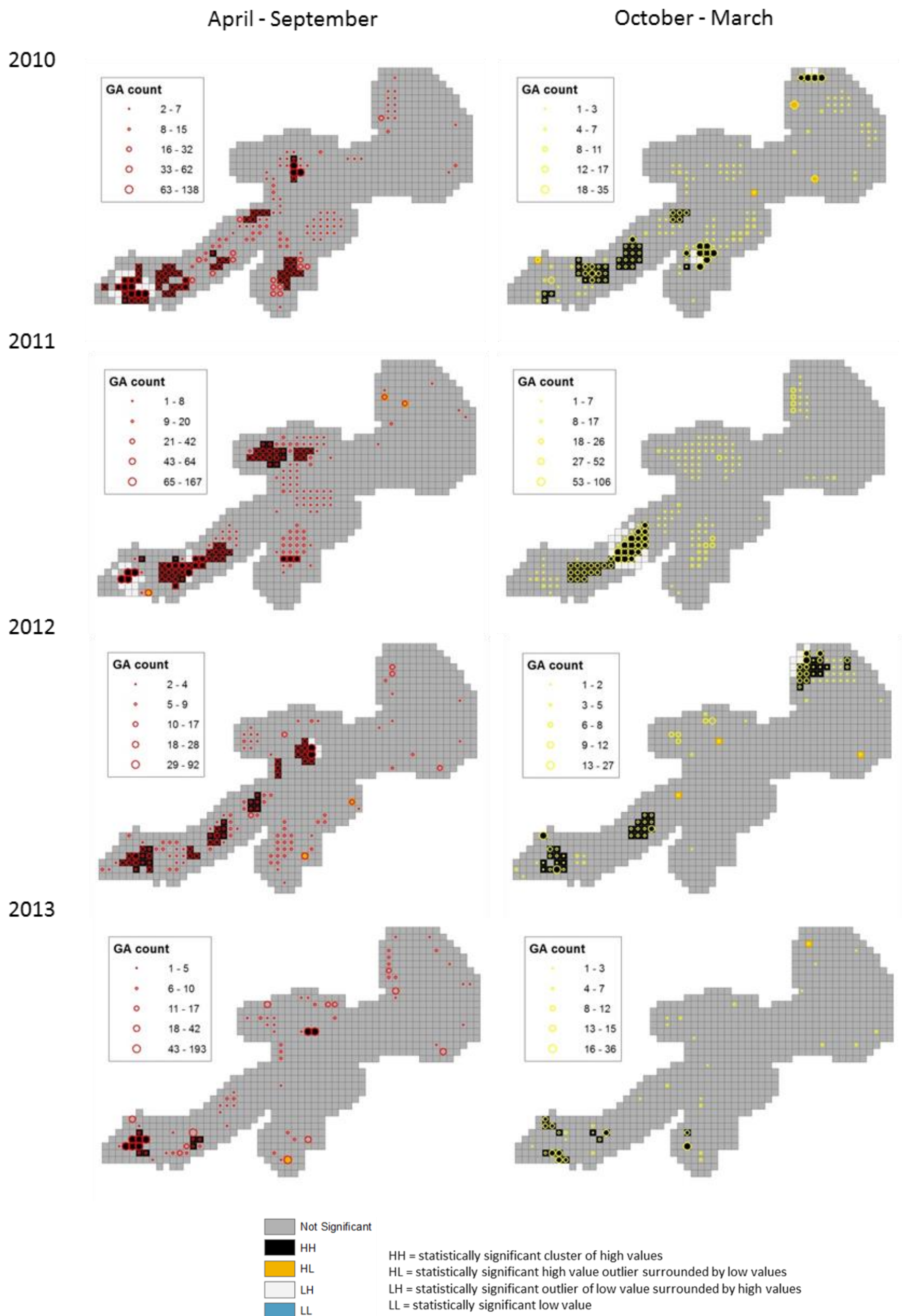


Figure 4.7: Spatial distribution of aggregated months (April- September and October-March) and Anselin Local Moran's I map output for Gadwall pre-construction (2006 – 2009). During April-September, the most significant clustering was observed for the Western Section and in 2009 when numbers peaked, the majority of Gadwall (1559 or 2060) birds were in the Central Section. During October-March, clusters of Gadwall were predominantly located within the Central Section and the shorelines of the Main Section.



4.3.3.3 Comparison of Gadwall distribution pre and during construction

Clustering of Gadwall occurred across all three sections during construction for the months April – September and was most pronounced within the Main Section (Figure 4.8). This corresponds with waterfowl counts which were significantly higher (Figure 4.9) within the Main Section during construction compared with pre-construction (Median pre-construction = 5.5, during construction = 75.5, Mann Whitney U_{175} , $p = < 0.05$). Significant differences were also observed during October – March with fewer Gadwall using Abberton Reservoir (all three sections combined) during construction (Median pre-construction = 110, during construction = 3.3, Mann Whitney U_{444} , $p = < 0.001$) and also within the Central Section (Median pre-construction = 278, during construction = 68.5, Mann Whitney $U_{456.5}$, $p = < 0.01$).

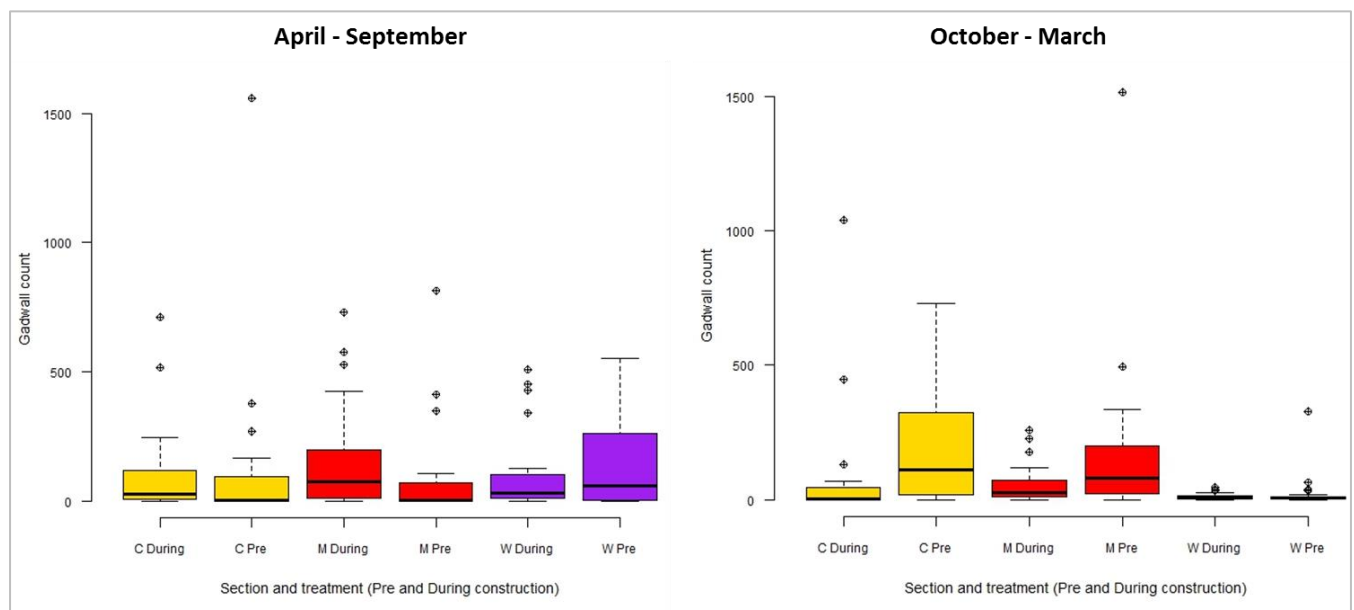


Figure 4.9: Comparison of Gadwall distribution pre and during construction during April – September and October – March across Abberton Reservoir (Main (M), Central (C) and Western (W) sections).

Key findings for Gadwall

1. During the spring and summer months pre construction, Gadwall were mostly aggregated into the Western Section which was less important during the winter months.

2. Use of the Main Section increased during construction compared with years pre-construction however overall, numbers of Gadwall at Abberton Reservoir during October – March (counts for all three sections combined) declined during construction.
3. For the winter months Gadwall counts were lower within the Central Section during construction.

4.3.3.4 Distribution of Shoveler pre-construction

Over the four years prior to construction activity there was spatial autocorrelation in the distribution of Shoveler. The largest proportion of Abberton Reservoir was classified as having non-significant clustering, which was most pronounced between clusters at distances of 300m. Outputs of Anselin Local Moran's I cluster and outlier analysis have been combined with Shoveler distribution across Abberton Reservoir and are shown in Figure 4.10.

During the months April through to September, significant clustering was observed for all three sections with a high proportion of those during 2008, occurring within the Main Section. For these spring and summer months, there were significant high clusters of Shoveler surrounded by low clusters i.e. outliers (shown by cells classified as HL). This result indicates that for these areas Shoveler were positioned within tight rafts and not distributed randomly across the water.

During the months October through to March, high clusters of Shoveler were densely distributed indicating large rafts of aggregated birds. Aside from Wigborough Bay in 2007, the majority of these clusters were within the Western and Central Sections with a few significantly high clusters surrounded by low clusters observed for the Main Section. Although not identified as significant, aggregations of Shoveler increased within the Main Section during 2009 with birds favouring the north aspect of the reservoir in addition to Hide Bay.

4.3.3.5 Distribution of Shoveler distribution during construction

During construction activity there was spatial autocorrelation in the distribution of Shoveler with the largest proportion of the reservoir classified as having non-significant clustering. With the exception of April – September 2013, the spatial dependence between Shoveler clusters was most pronounced at distances of 300m. Shoveler distribution and outputs of Anselin Local Moran's I cluster and outlier analysis for the years during construction are shown in Figure 4.11.

During April through to September, significant dense clustering occurred within all three sections, with Shoveler particularly favouring the areas of Hide and Wigborough Bays during 2011 and 2013. For all four years during construction and with the exception of a few tight rafts (outliers indicated by HL classification), very few Shoveler were positioned within the northern parts of the Main Section.

For the months of October through to March, significant high clusters were observed for all three sections. During 2010, Shoveler were predominantly within the Western Section, Hide Bay and on the north-east corner of the main dam (Main Section). Dense significant clusters also appeared across the Main and Western Sections during 2011 with very few observed for the Central Section. Although not identified as significant, aggregations of Shoveler during 2012 were similar to those seen during 2011 and 2013 (Figure 4.11).

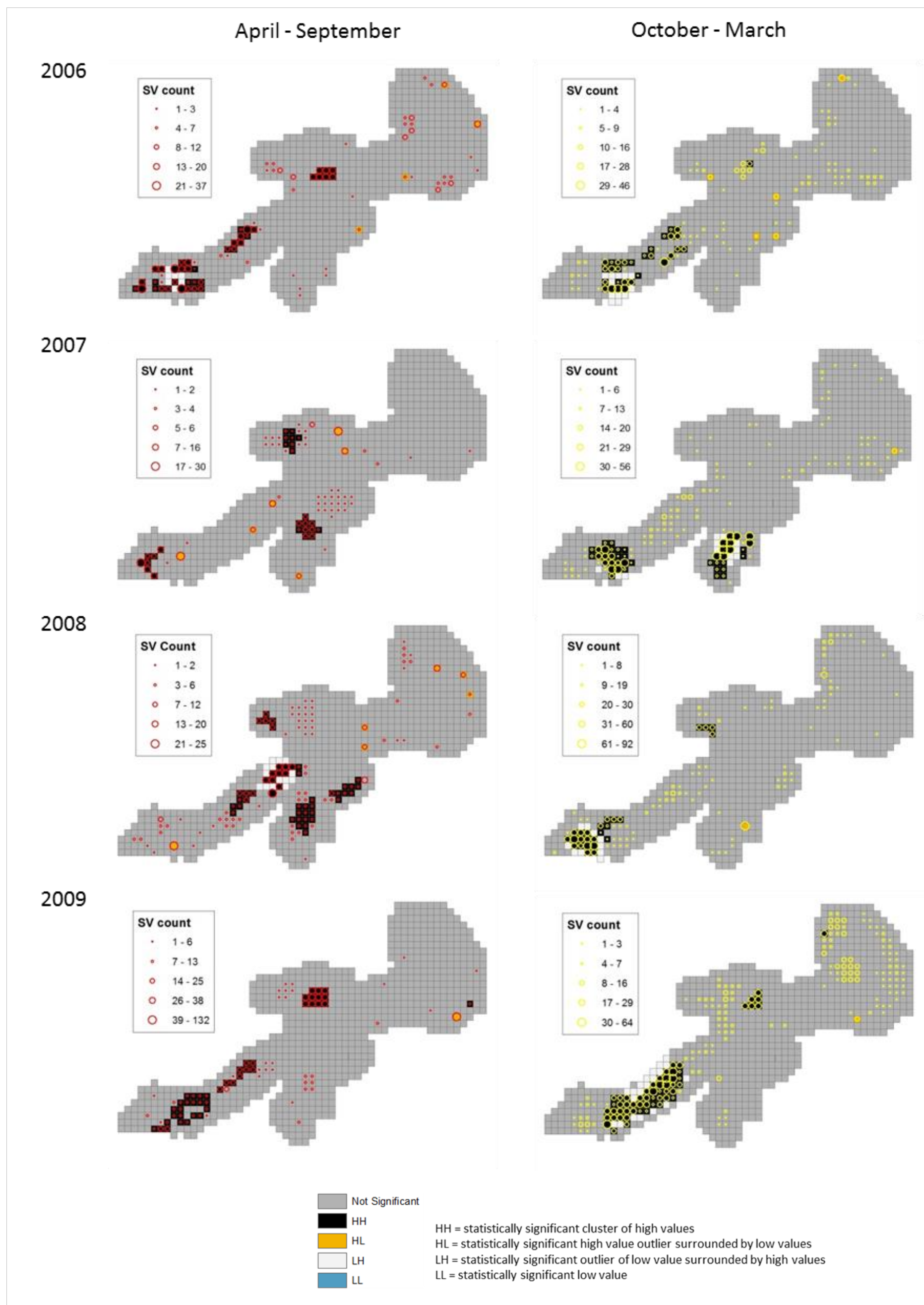
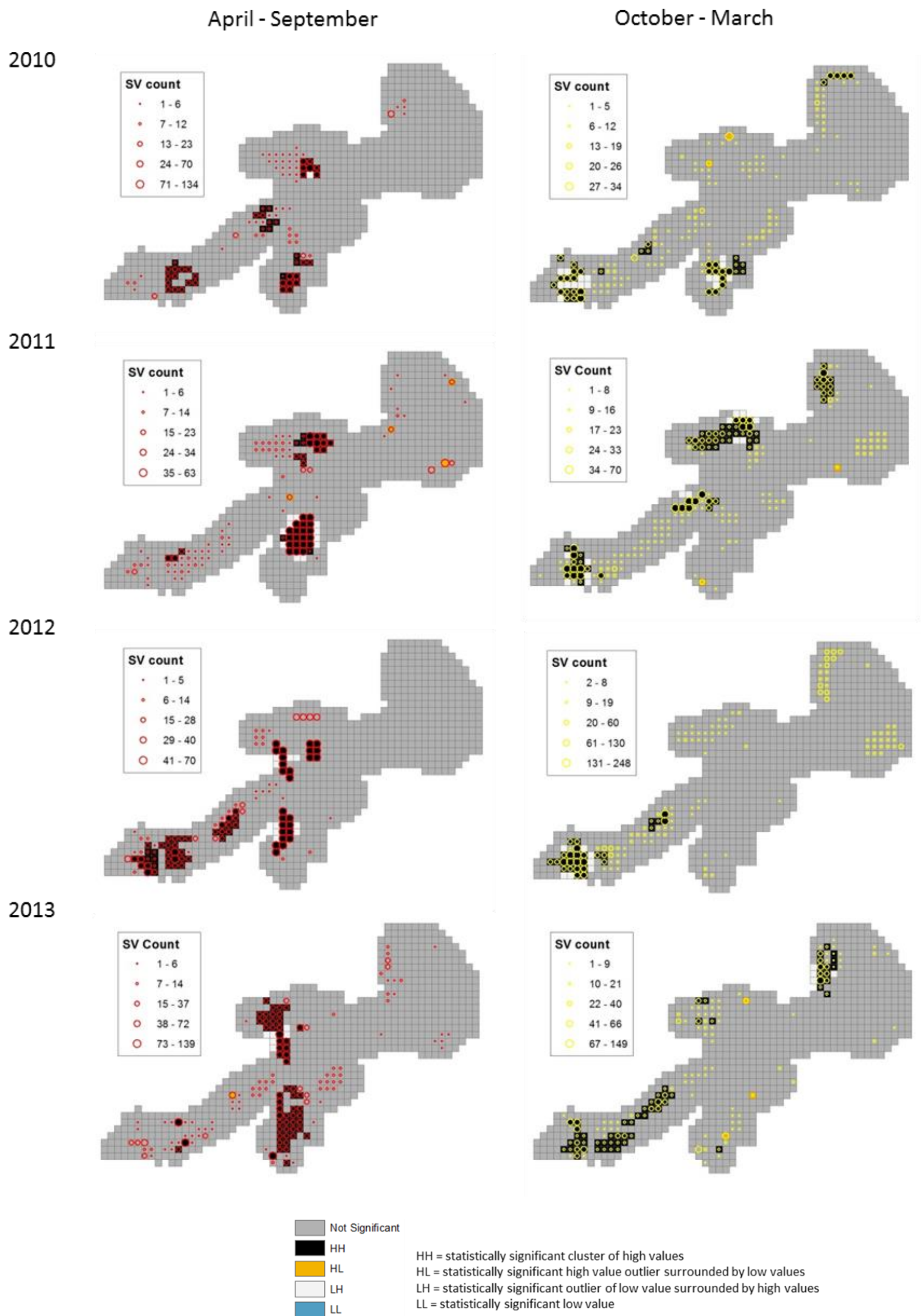


Figure 4.10: Spatial distribution of aggregated months (April- September and October-March) and Anselin Local Moran's I map output for Shoveler pre construction (2006 – 2009). Distribution patterns of Shoveler were similar to Gadwall with preferred areas located within Hide Bay and Wigborough Bay as well as the Western Section and parts of the north aspect of the Central Section.



4.3.3.6 Comparison of Shoveler distribution pre and during construction

During the combined months of April – September, Shoveler counts within the Central Section were significantly higher during construction ((Figure 4.12), median pre-construction = 0, during construction 12, Mann Whitney U_{189} , $p = < 0.05$). When all sections were combined to represent Abberton Reservoir as a total site, Shoveler distributions also significantly increased during construction (Median pre-construction = 16, during construction = 83, Mann Whitney $U_{191.5}$, $p = < 0.05$).

The only significant difference observed for the months October through March was for the Western Section, for which Shoveler distributions were higher during construction (Median pre-construction = 8.5, during construction = 23, Mann Whitney U_{180} , $p = < 0.05$).

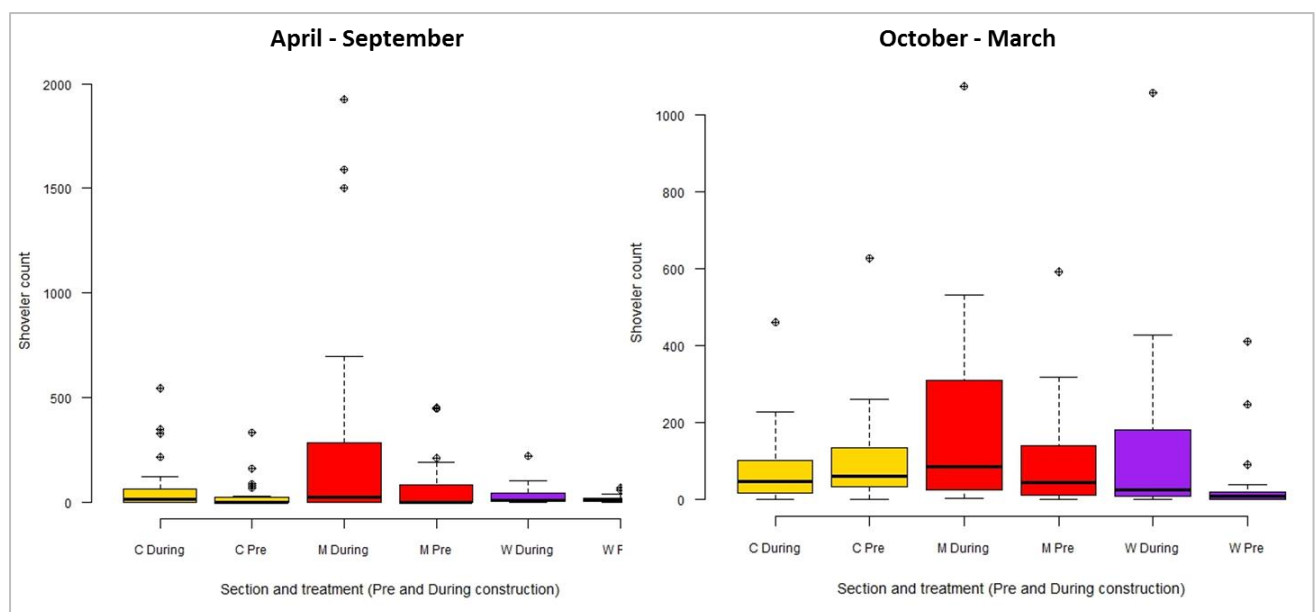


Figure 4.12: Comparison of Shoveler distribution pre and during construction during April – September and October – March across Abberton Reservoir (Main (M), Central (C) and Western (W) sections).

Key findings for Shoveler

1. During the spring and summer months, numbers of Shoveler increased across Abberton Reservoir (counts for all sections combined), particularly within the Central Section which showed a significant increase in years during construction.

2. Within the Main Section, particularly in years during construction, Shoveler favoured areas within Hide Bay, Wigborough Bay and along parts of the north-west shoreline.
3. For the autumn and winter months, Shoveler showed a preference for the Western Section and numbers significantly increased during construction compared with years pre-construction.

4.3.3.7 Distribution of Teal pre-construction

Over the four years prior to construction activity, the distribution of Teal exhibited spatial autocorrelation indicating this species was not distributed across the reservoir in a random manner. In all four years, the majority of Abberton Reservoir was classified as having non-significant clustering. Ripley's K-Function identified a general pattern of significant clustering from the Teal count data which was most pronounced between clusters at 300m and 500m.

Outputs of Anselin local Moran's I cluster and outlier analysis have been combined with Teal distribution across Abberton Reservoir (Figure 4.13). During 2006, the only significantly grouped cells exhibiting concentrated clustering were observed for the Western Section, although significantly high clusters surrounded by low clusters (outliers) were seen for both the Main and Central Sections. Similar to Shoveler, this indicates tight rafts of Teal were present in these areas. During 2007, there were no significant clusters of Teal along the northern parts of the reservoir (within all three sections) and the only significant aggregations were slightly outside of the Wigborough Bay area. This area contained significant aggregations during 2008 although clusters were also present within the Central Section. During 2009, Teal were clustered, albeit limited in spatial extent, within all three sections of the reservoir with the highest concentration slightly east of Hide Bay.

For the months of October - March, the Central Section dominated with the majority of significant aggregations observed for this section. Within the Central Section, clusters of Teal were positioned along the shoreline of both the northern and southern sides and were surrounded by cells

categorised as having low clustering (LH). Compared with the spring/summer months, total numbers of Teal increased during the autumn/winter; shown by the increased number of cells categorised as having significant clustering.

4.3.3.7 Distribution of Teal during construction

Over the four years during construction Teal displayed spatial autocorrelation with the majority of Abberton Reservoir classified as having non-significant clustering. This was most pronounced between each cluster at distances of 200m and 500m.

During construction and for months April through to September, Teal favoured Hide and Wigborough Bay, with the percentage of cells classified as HH increasing compared with years pre-construction (Appendix 4.3). With the exception of one HH cell observed for 2013, significant high clusters of Teal were absent from the Central and Western Sections (Figure 4.14). This category of cell was also absent for the north-east parts of the Main Section although some outliers (HL) were observed during 2012 and 2013 indicating isolated dense rafts of Teal were present at this time.

During October through to March, Teal aggregations increased in comparison with the pre-construction years with significant high clusters observed within the Main Section. During 2010 and to a lesser degree 2013, cells categorised as LH (low value cells surrounded by high value cells) were particularly evident for the Wigborough Bay area. This indicates that the birds were positioned within dense aggregations, most likely as a roost flock.

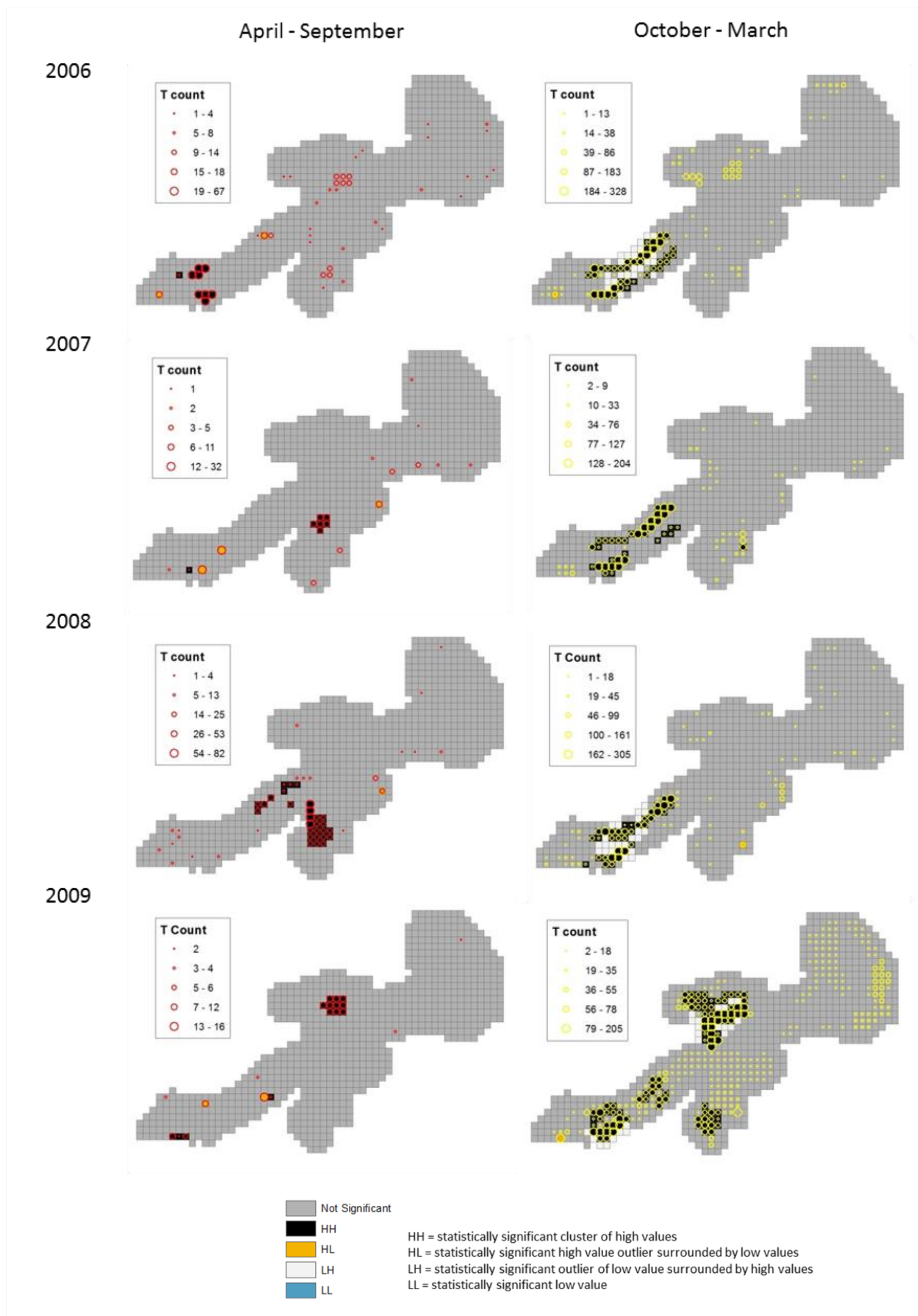
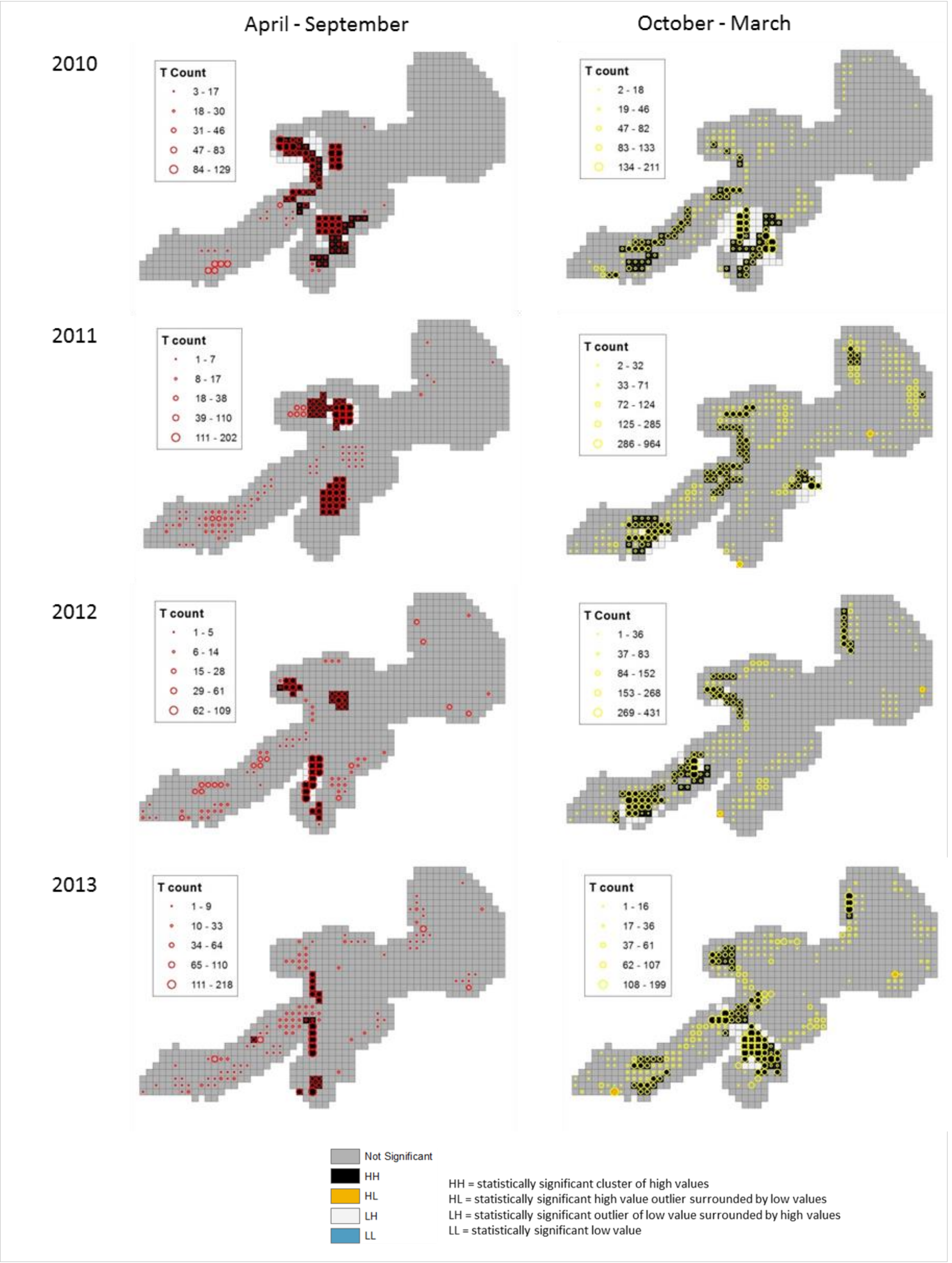


Figure 4.13 Spatial distribution of aggregated months (April- September and October-March) and Anselin Local Moran's I map output for Teal pre-construction (2006 – 2009). For months April-September there were no obvious patterns in Teal distribution yet aggregations for October-March were dense, particularly within the Central Section and in 2009, Hide Bay.



4.3.3.8 Comparison of Teal distribution pre and during construction

During the combined months of April – September, Teal counts (Figure 4.15) within the Central Section were significantly higher during construction (Median pre-construction = 0, during construction = 11.5, Mann Whitney U_{195} , $p = < 0.05$). When all sections were combined to represent Abberton Reservoir as a total, Teal also significantly increased during construction compared with pre-construction (Median pre-construction = 1.5, during construction = 52, Mann Whitney $U_{179.5}$, $p = < 0.05$).

For the months October through to March, numbers of Teal within the Main Section significantly increased during construction compared to years pre-construction (Median pre-construction = 65, during construction = 1165, Mann Whitney $U_{111.5}$, $p = < 0.01$). There was also a significant increase during construction when all sections were combined to represent Abberton Reservoir in total (Median pre-construction = 867, during construction = 1736.5, Mann Whitney U_{184} , $p = < 0.05$).

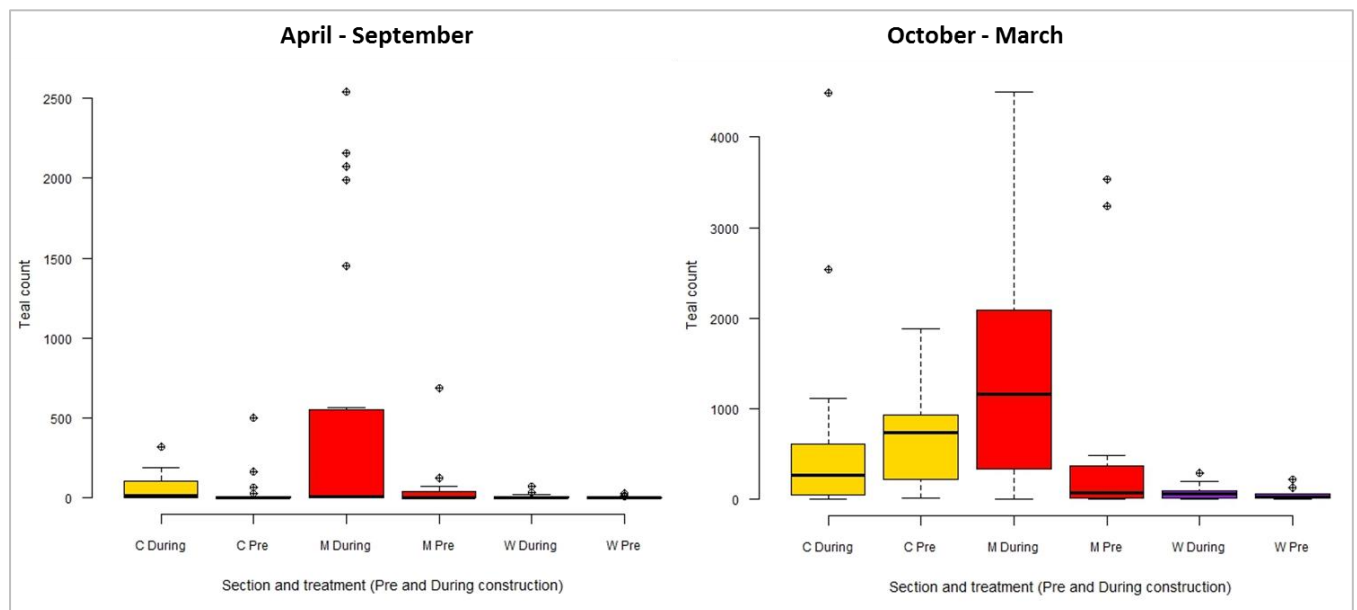


Figure 4.15: Comparison of Teal distribution pre and during construction during April – September and October – March across Abberton Reservoir (Main (M), Central (C) and Western (W) sections).

Key findings for Teal

1. Numbers of Teal were significantly higher in years during construction.

2. Teal using Abberton Reservoir aggregated within dense rafts.
3. Teal used the Central Section to a greater extent in the spring/summer months during construction, but favoured the Main Section shorelines during the autumn/winter months.

4.3.3.9 Distribution of Wigeon pre-construction

Over the four years prior to construction activity, Wigeon displayed spatial autocorrelation which was most pronounced (cluster to cluster), between distances of 300m and 500m. In all four years (2006 - 2009), the majority of Abberton Reservoir was classified as having non-significant clustering. Outputs of Anselin local Moran's I cluster and outlier analysis and Wigeon distribution across Abberton Reservoir are shown in Figure 4.16.

During the months April through to September for years 2006 and 2009, the only significant clusters were observed for the Central and Western Sections. 2009 had very low Wigeon aggregations, particularly in comparison with the previous two years. The highest number of significant clusters and also the highest aggregations of Wigeon were seen during 2008 with birds mainly situated within the Hide and Wigborough Bay areas; areas also favoured by the other dabbling duck species.

During October through to March, the Central Section for all years contained a high proportion of aggregations categorised as significant high clusters (HH) surrounded by low value cells (LH), indicating dense rafts of Wigeon were present. This HH, LH pattern was also observed for the Wigborough Bay area during 2008 with another substantial area of HH cells located in Hide Bay, although unlike Wigborough Bay these are surrounded by cells containing Wigeon (but not classified as significant).

4.3.3.10 Distribution of Wigeon during construction

Over the four years during construction Wigeon exhibited spatial autocorrelation in their distribution which was most pronounced from cluster to cluster between distances of 100m and 300m. In all four years the majority of Abberton Reservoir was classified as having non-significant clustering.

Figure 4.17 shows Wigeon distribution and the outputs of Anselin local Moran's I cluster and outlier analysis. During construction for the months April through to September, Wigeon showed a preference for the Central Section, Wigborough Bay and Hide Bay which was also seen in years pre-construction. During 2011 and 2013, the greatest extent of high value cluster cells was observed for Hide Bay, which during 2011 extended to form an additional large cluster between Hide and Wigborough Bay. Aggregations of Wigeon were particularly low during 2012 and although significant high clusters were seen in all three sections, they were small in spatial extent.

During October through to March, the majority of significant high clusters seen across the Main Section. During 2012, 2013 and to a lesser extent 2011, high concentrations of significant clusters were located to the west of the main dam (Figure 4.17). With the exception of 2010, Hide Bay and the north-west shoreline were particularly important for this species with significant clusters seen throughout these areas. During 2012 and 2013, Wigeon were fairly absent from the Central Section and only non-significant aggregations were present within the Western Section.

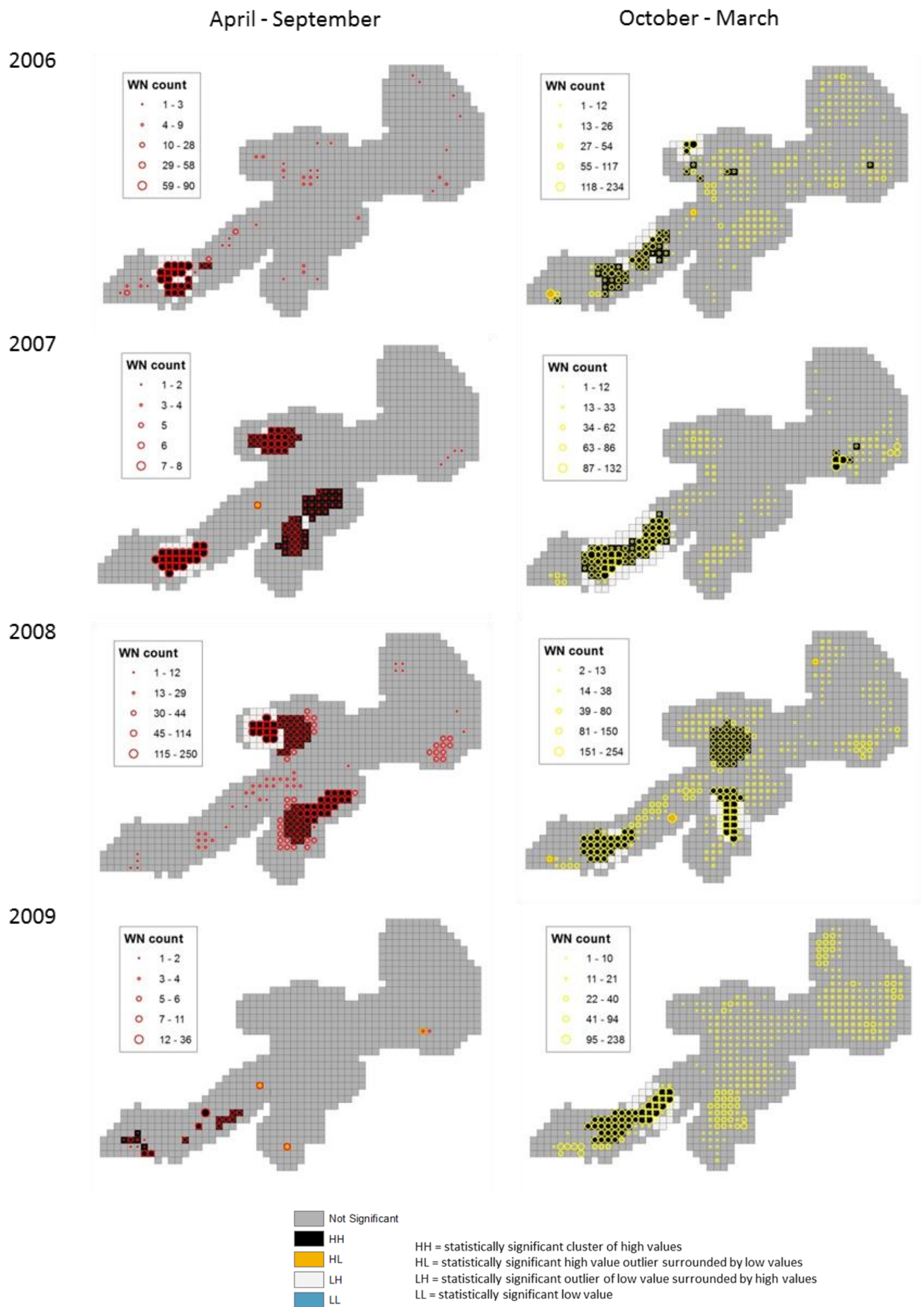


Figure 4.16 Spatial distribution of aggregated months (April- September and October-March) and Anselin Local Moran's I map output for Wigeon pre-construction (2006 – 2009). Aggregations of Wigeon were more dispersed during the autumn/winter months compared with spring/summer and dense aggregations were observed for the Central Section; an area not particularly favoured in April-September.

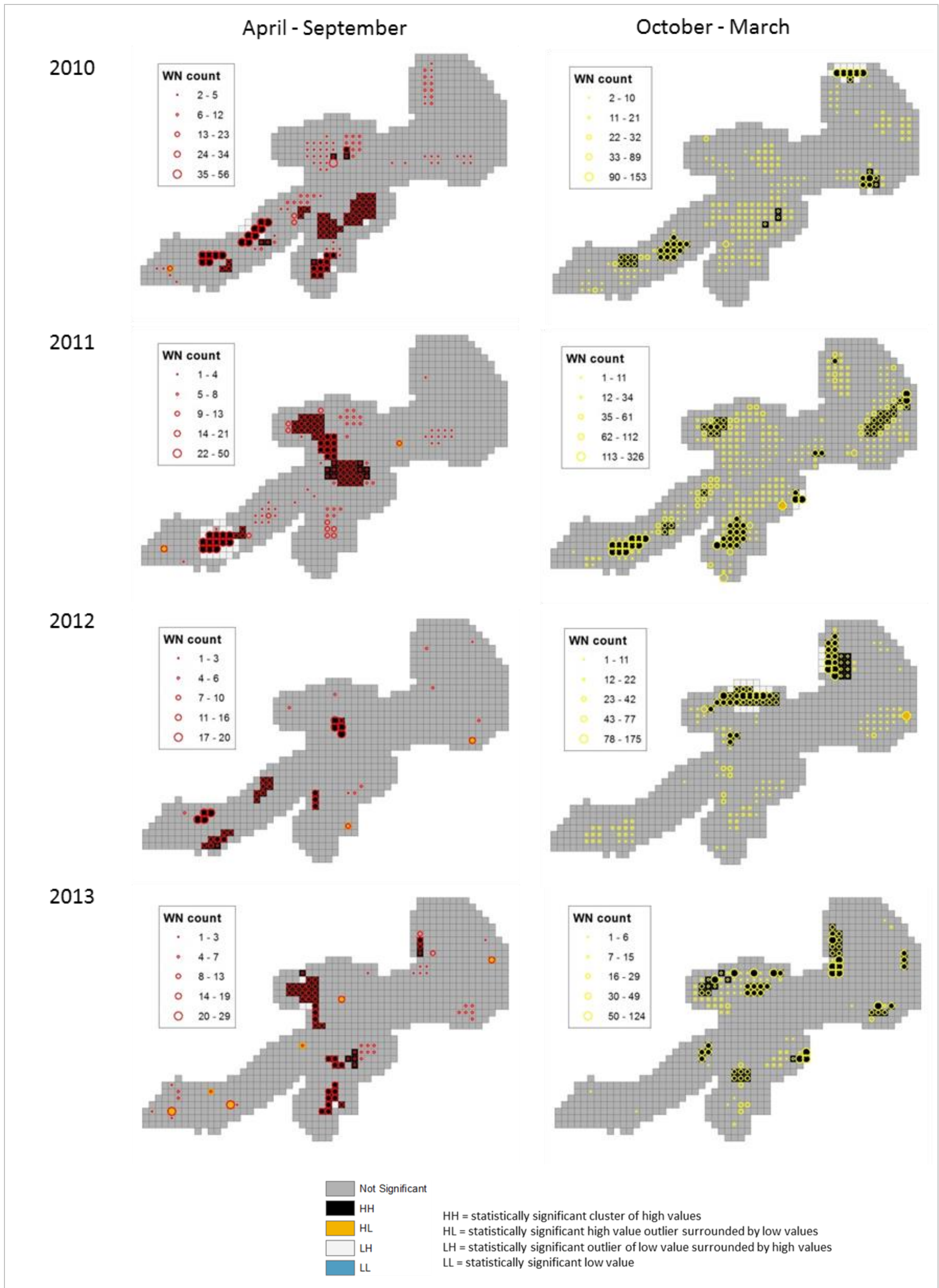


Figure 4.17 Spatial distribution of aggregated months (April- September and October-March) and Anselin Local Moran's I map output for Wigeon during construction (2010 – 2013). During construction, aggregations of Wigeon were higher during October-March than observed for the April/September period yet for both temporal periods, Hide Bay contained dense aggregations.

4.3.3.11 Comparison of Wigeon distribution pre and during construction

During the combined months of April – September (Figure 4.18), Wigeon showed a similar pattern to Teal, with distributions within the Main Section significantly higher during construction (Median pre-construction = 0, during construction = 8.5, Mann Whitney $U_{155.5}$, $p < 0.01$). When all sections were combined to represent Abberton Reservoir as a total, distributions significantly increased during construction compared with pre-construction (Median pre-construction = 4, during construction = 16, Mann Whitney $U_{195.5}$, $p < 0.05$).

For the months October through to March, significant differences were observed for both the Central and Western Sections in which aggregations decreased during the construction period (Central Section: median pre-construction = 230, during construction = 0, Mann Whitney U_{433} , $p < 0.01$). For the Western Section this difference was highly significant (Median pre-construction = 45, during construction = 1, Mann Whitney U_{517} , $p < 0.001$).

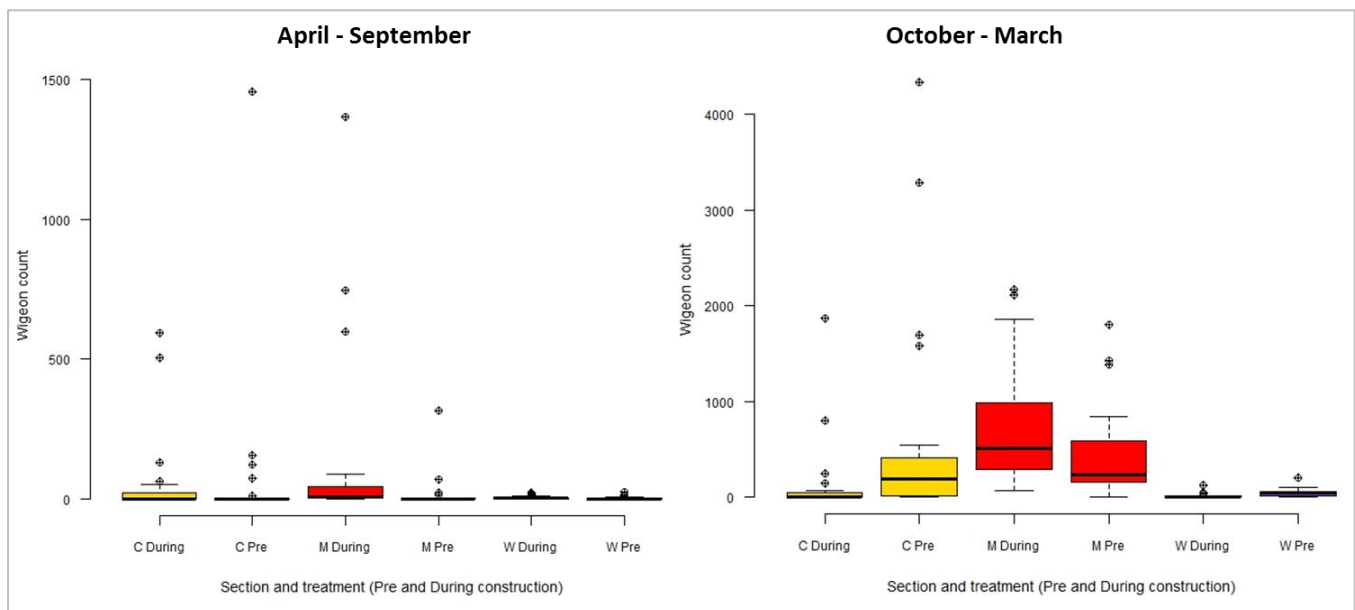


Figure 4.18: Comparison of Wigeon distribution pre and during construction during April – September and October – March across Abberton Reservoir (Main (M), Central (C) and Western (W) sections).

Key findings for Wigeon

1. During the spring and summer months, numbers of Wigeon were significantly higher in the Main Section and across Abberton Reservoir for years during construction.
2. Numbers of Wigeon during the winter months declined within the Central and Western Section during construction, with an increase of use seen for the Main Section (non-significant), particularly in the shoreline areas.

4.3.3.12 Distribution of Coot pre construction

Over the four years prior to construction activity, the distribution of Coot exhibited spatial autocorrelation and were not distributed across the reservoir in a random manner. In all four years, clustering between aggregations of Coot was most pronounced at 300m, with the majority of Abberton Reservoir classified as having non-significant clustering. Outputs of Anselin Local Moran's I cluster and outlier analysis and Coot distribution across Abberton Reservoir are shown in Figure 4.19.

For months April through to September, the extent of high value clusters increased as the years progressed with 11% of cells represented by this cluster type observed for 2008 and 2009 (Appendix 4.3). Throughout the pre-construction years, the Western Section, Hide Bay and areas extending from Hide Bay into the centre of the reservoir were particularly important. The distribution of Coot within these areas was similar for years 2008 and 2009.

During October through to March (2006 – 2009), much of the reservoir contained significant Coot aggregations however the Western Section became less important. Areas dominated by significant clusters were the Central Section and Wigborough Bay although during 2007, Hide Bay also contained significant high clusters. During 2007 and 2008, highly clustered areas were also surrounded by areas with low values suggesting that for these years and areas, Coot were aggregated in a particularly dense manner.

4.3.3.13 Distribution of Coot distribution during construction

Over the four years during construction, there was autocorrelation in the spatial distribution of Coot with the majority of Abberton Reservoir classified as having non-significant clustering. Ripleys K-Function identified that spatial processes between clusters were most pronounced between distances of 300m and 500m. Figure 4.20 shows Coot distribution and the outputs of Anselin local Moran's I cluster and outlier analysis during construction.

During 2010, for the months April through to September, significant clusters of Coot were observed within all three sections with the majority seen across the Central Section and within Hide Bay. Significant clusters were also present on the south-east area of the Main Section and to the west of the main dam. Although aggregations were present throughout 2011 and 2013, key areas for Coot were Hide and Wigborough Bay and to a lesser extent during 2013, the Central Section. 2012 is interesting in that all cells classified as having HH values were located in a vertical pattern between Hide and Wigborough Bays. These high clusters were also surrounded by LH cells; suggestive of dense clustering.

During months October to March LL cells (cells of low value surrounded by cells of low value) were present for years 2010, 2011 and 2013. These cells represent cold spots where there was a significant lack of Coot compared to the rest of the reservoir. The Western Section, small areas of Wigborough Bay and areas in the south-east section of the Main Section all contained these cold spots. In 2013, the distribution of Coot within the Main Section differed from that of other years with significant clusters distributed across the north and east parts of the Main Section. 2012 appears more representative of distributions seen during for months April - September and that across pre-construction years with the majority of Coot clusters within the Central Section and Hide Bay.

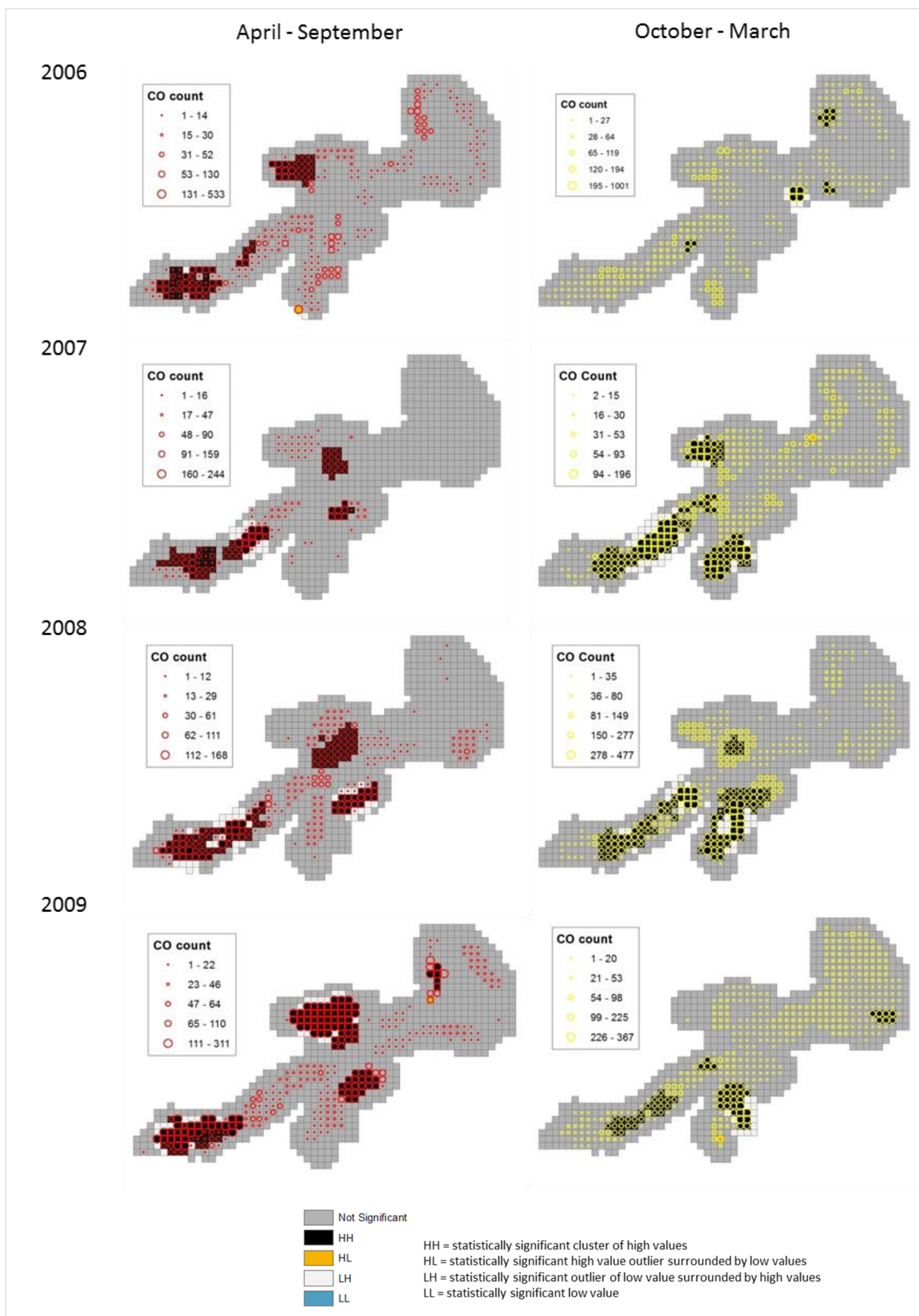


Figure 4.19 Spatial distribution of aggregated months (April- September and October-March) and Anselin Local Moran's I map output for Coot pre-construction (2006 – 2009). Across both temporal periods, the Western Section, Central Section and Hide Bay contained dense aggregations of Coot.

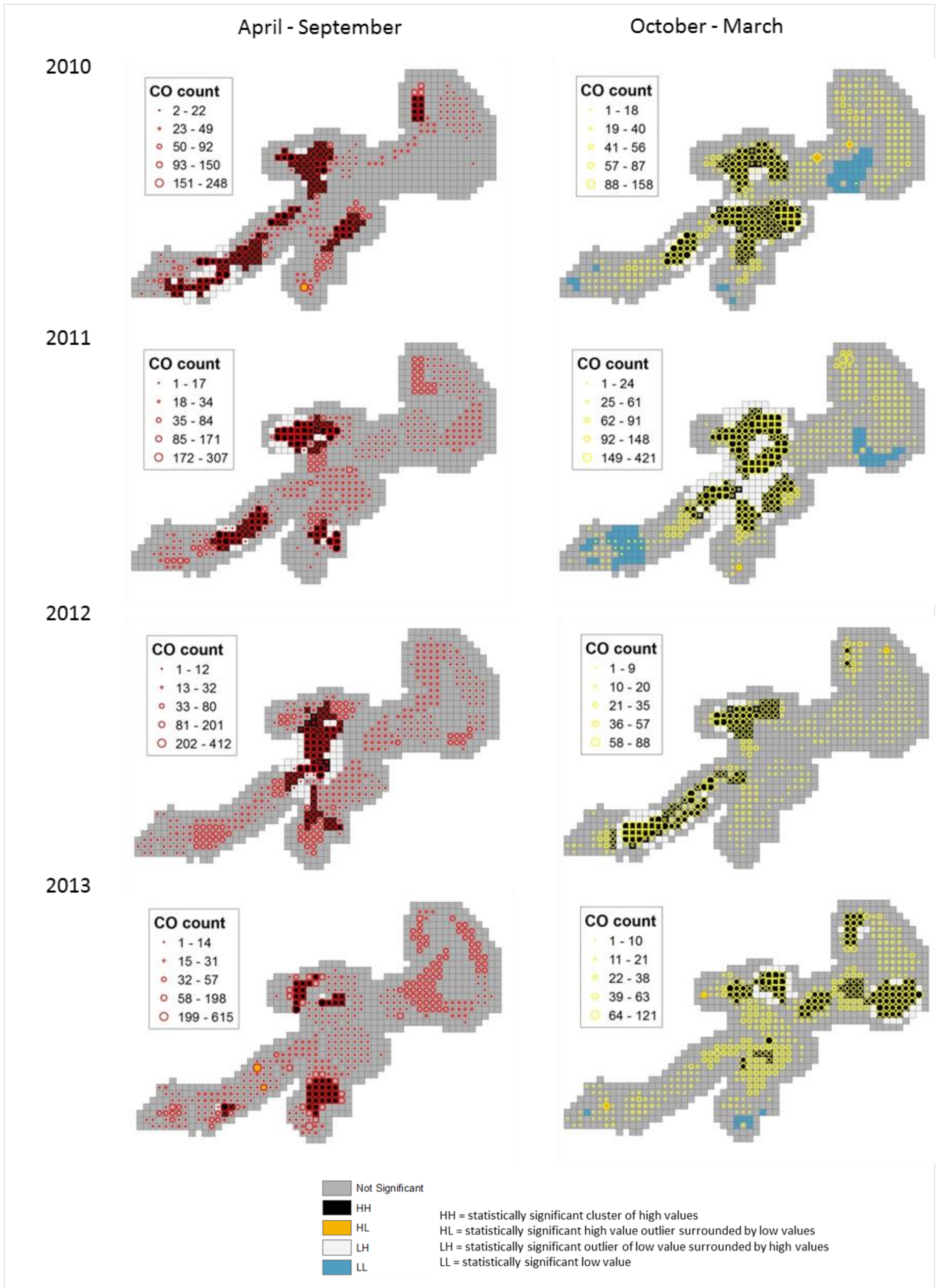


Figure 4.20 Spatial distribution of aggregated months (April- September and October-March) and Anselin Local Moran's I map output for Coot during construction (2010 – 2013). With the exception of 2012, during October-March the majority of dense Coot clusters were located within the Main Section; different from patterns observed during April-September.

4.3.3.14 Comparison of Coot distribution pre and during construction

During the combined months of April – September, Coot distributions (Figure 4.21) within the Main Section were significantly higher during construction compared with years pre-construction (Median pre-construction = 23, during construction 313, Mann Whitney $U_{157.5}$, $p = < 0.01$).

For the months October to March, significant differences were observed for the Central Section which were shown to decrease during construction (Central Section: median pre-construction = 233.5, during construction = 66.5, Mann Whitney U_{402} , $p = < 0.01$).

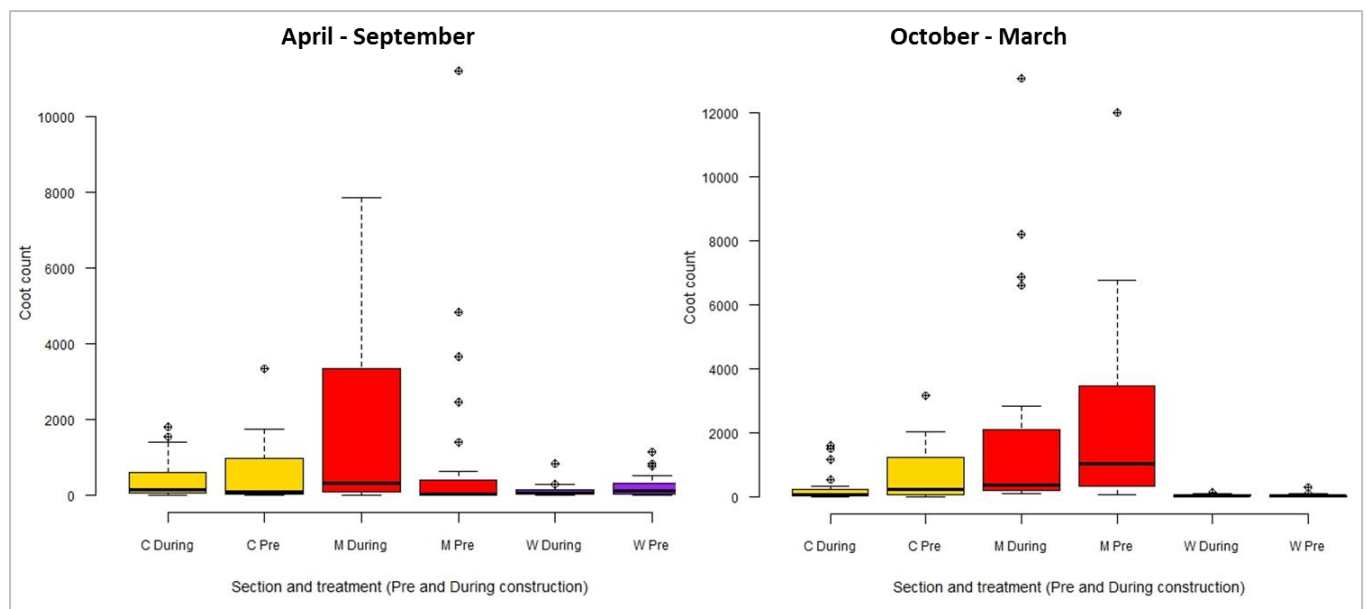


Figure 4.21: Comparison of Coot distribution pre and during construction during April – September and October – March across Abberton Reservoir (Main (M), Central (C) and Western (W) sections).

Key findings for Coot

1. During the spring and summer months numbers of Coot were higher within the Main Section for years during construction.
2. During construction for months October – March, the majority of Coot clusters were within the Main Section but numbers were lower in this section than in years pre-construction (non-significant difference).

3. Coot numbers significantly declined during construction within the Central Section for months October – March.
4. Areas of water within all three sections for autumn/winter contained significant cold spots.

4.3.3.15 Distribution of Tufted Duck distribution pre-construction

Prior to construction activity, distributions of Tufted Duck exhibited spatial autocorrelation and were not distributed randomly across the reservoir. In all four years Abberton Reservoir was classified as having non-significant clustering which was most pronounced between clusters at distances of 200m and 300m.

Figure 4.22 shows the outputs of Anselin Local Moran's I cluster and outlier analysis combined with Tufted Duck distribution. During April through to September 2006 and 2007, Hide Bay, parts of Wigborough Bay and the Western Section all contained significant high value clusters of Tufted Duck. During 2007, significant clusters of Tufted Duck were absent from the Central section and also across the north-east areas of the Main Section. In contrast, this area within the Main Section was important for this species during 2008 and 2009.

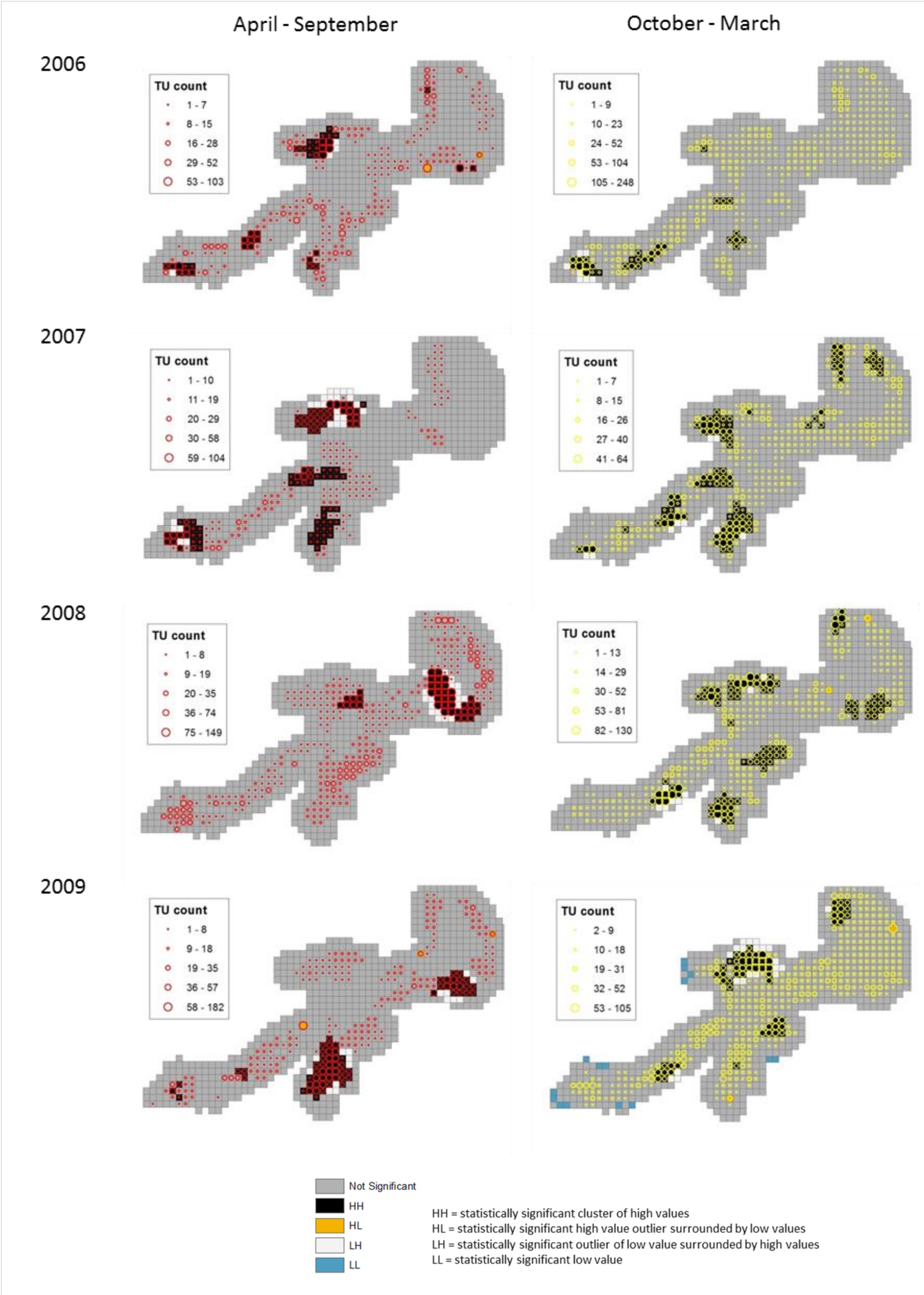
During October to March 2006, there were fewer significantly high value clusters compared with the other years. However, the aggregations (Figure 4.22) indicate that whilst the majority of clusters were not significant, they were high in Tufted Duck counts compared to the other years; suggestive of a more dispersed pattern of distribution. For years 2007 through to 2009, the Western Section was less occupied compared to the other sections and the majority of Tufted Duck were located within the Main Section. During 2009, cold spots (represented by LL cells) were present within the Western and Main Sections which may be a result of a particularly even distribution observed within the rest of reservoir complex.

4.3.3.16 Distribution of Tufted Duck distribution during construction

Over the four years during construction there was spatial autocorrelation in the distribution of Tufted Duck with the majority of Abberton Reservoir (all three sections combined and across 797 100m² cells) classified as having non-significant clustering which was found to be most pronounced between clusters at distances of 100m and 300m.

Figure 4.23 shows Tufted Duck distribution and the outputs of Anselin local Moran's I cluster and outlier analysis for years during construction. During April through to September 2010 and 2011, significantly high clusters of Tufted Duck were observed for the Main Section. This is in contrast with 2012 and to a lesser extent 2013 where significant clusters were mainly absent from this section. In 2012, the majority of clusters were located within the Central Section and in 2013, a general lack of clustering was observed across the whole reservoir.

During October through to March, significantly high value cells were predominately located in the Main Section with preferences seen for Hide Bay, west of the main dam and an area slightly north of Wigborough Bay. For these months and in all years, the same cells at the Western Section contained aggregations of Tufted Duck; in 2010 and 2012 these aggregations were classified as significant clusters and for 2011 and 2013 they were non-significant (Figure 4.23).



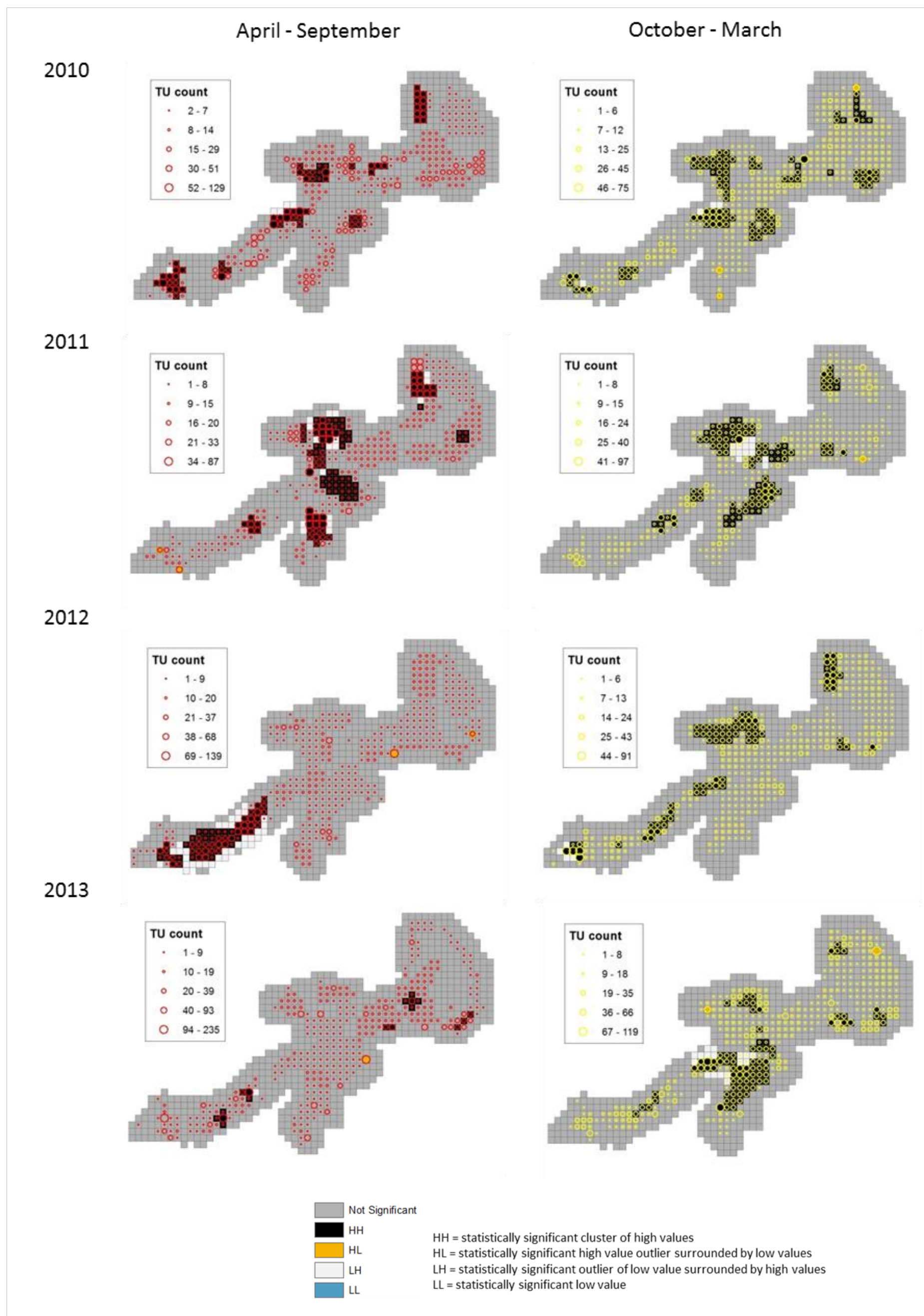


Figure 4.23 Spatial distribution of aggregated months (April- September and October-March) and Anselin Local Moran's I map output for Tufted Duck during construction (2010 – 2013). Similar to years pre-construction and to other waterfowl species, Tufted Duck showed a preference to aggregate in Hide Bay and within the area located west of the main dam.

4.3.3.17 Comparison of Tufted Duck distribution pre and during construction

The only significant differences in Tufted Duck (Figure 4.24) were observed for the months of October to March, where numbers within the Central Section were significantly lower during construction compared with years pre-construction (Median pre-construction = 108.5, during construction = 66.5, Mann Whitney $U_{402.5}$, $p = < 0.01$). Overall, across the reservoir complex Tufted Duck distributions differed pre-construction compared with during construction with higher numbers observed pre-construction (Median pre-construction = 1011.5, during construction = 586, Mann Whitney U_{406} , $p = < 0.01$).

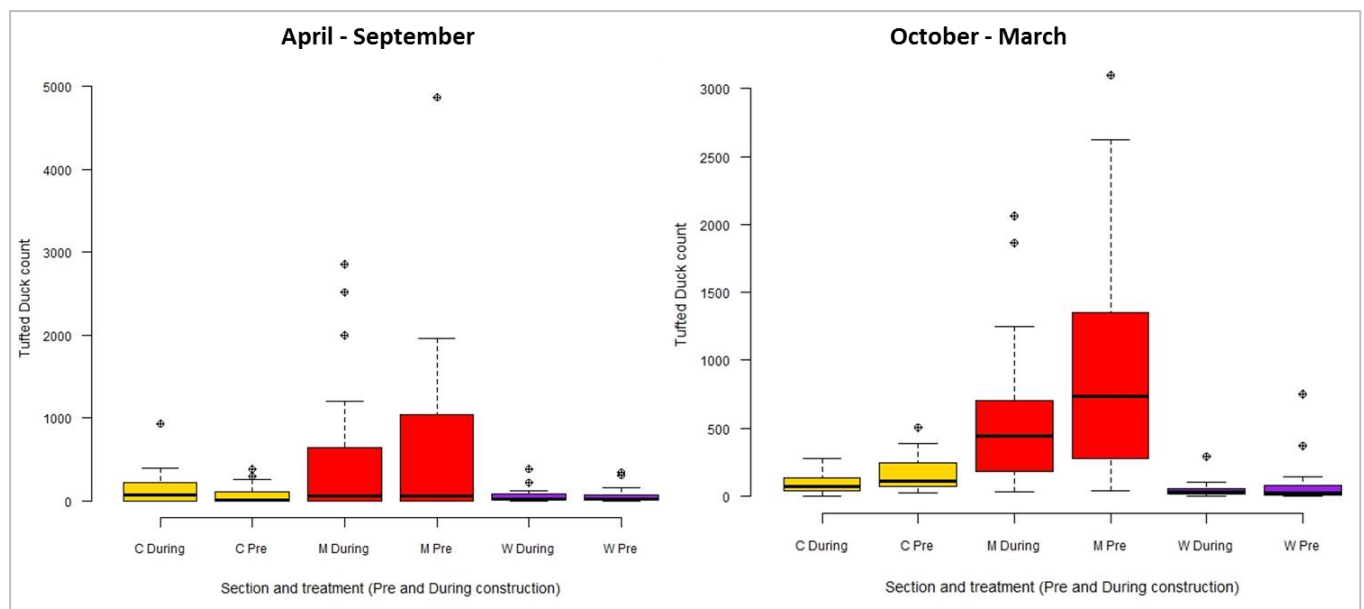


Figure 4.24: Comparison of Tufted Duck distribution pre and during construction during April – September and October – March across Abberton Reservoir (Main (M), Central (C) and Western (W) sections).

Key findings for Tufted Duck

1. The only significant differences were found for the autumn and winter months where Tufted Duck were present in significantly higher numbers across Abberton Reservoir and in the Central Section in years pre –construction.
2. Tufted Duck numbers also declined in the Main Section during construction, although any differences were non-significant.

3. Generally this species was fairly well distributed across the reservoir in all years with a consistent preference in the Main Section for Hide Bay.

4.3.3.18 Distribution of Pochard pre construction

In years prior to construction activity, Pochard exhibited spatial autocorrelation which was most pronounced between clusters at distances of 200m and 300m. Figure 4.25 shows the outputs of Anselin Local Moran's I cluster and outlier analysis combined with Pochard distribution. For the months April through to September, Pochard did not show any consistent pattern of distribution although significant clustering was observed for the Western Section. During 2008, the HH cells within the Main Section indicating high clustering of Pochard are similar to that observed for Tufted Duck. During 2008, the whole of the eastern extent of the Main Section was particularly important for this species, illustrated by the high proportion of cells classified as HH. The LH cells present within this area are also indicative of dense clustering.

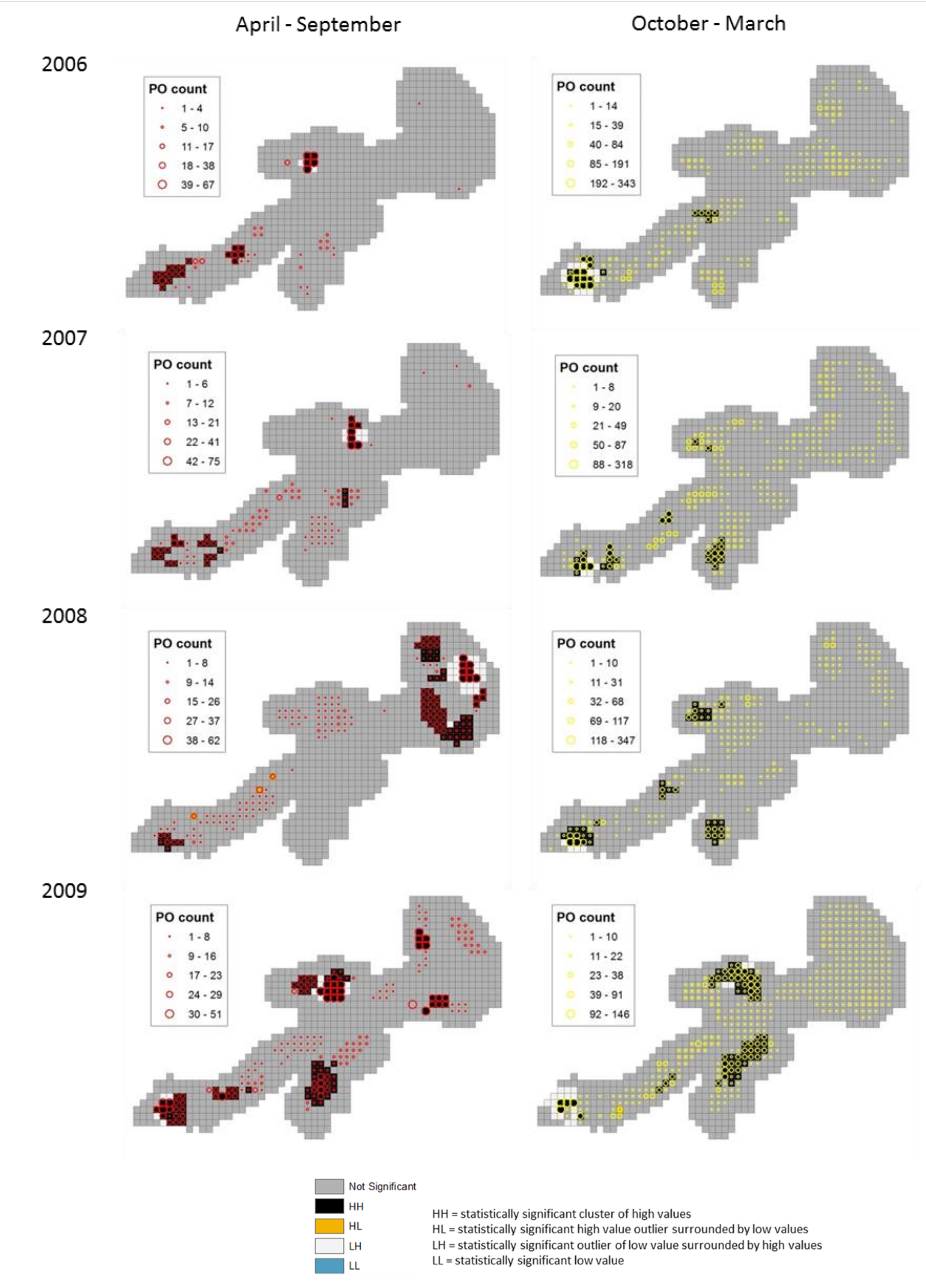
During the months October through to March, the Western Section was consistently used by Pochard for which significant clustering was observed. During 2007 and 2008, key areas for this species within the Main Section were Wigborough and Hide Bays (Figure 4.25). Analysis revealed clustering was lowest for 2006 and highest for 2009 during which Pochard aggregations, although non-significant, are fairly well distributed across the Main Section.

4.3.3.18 Distribution of Pochard during construction

Over the four years during construction, there was autocorrelation in the spatial distribution of Pochard which was most pronounced between clusters at distances of 100m and 300m. Figure 4.26 shows Pochard distribution and the outputs of Anselin Local Moran's I cluster and outlier analysis for years during construction.

The pattern for April through to September during 2011 is very similar to that observed during 2008 although in 2011, Hide Bay also contained cells classified as HH. These high clusters are surrounded by cells with an LH classification, indicative of dense clustering surrounded by areas lacking birds. During 2011, there was also a distinct lack of significant clustering within the other two sections with birds aggregated into much smaller flocks. During 2010, the Western and Central Sections were primarily important and in 2012 and 2013 all three sections contain cells classified as HH. These were however, more widely dispersed compared to other years.

During October through to March, aggregations of Pochard were well distributed throughout the reservoir. The Western Section and for the most part the Central Section, held significant clusters with the Central Section holding the majority of Pochard during 2013 (Figure 4.26). It appears that for this species (during October through to March), the area of Wigborough Bay was not a preferred location. This is in contrast to years pre-construction and also to other species.



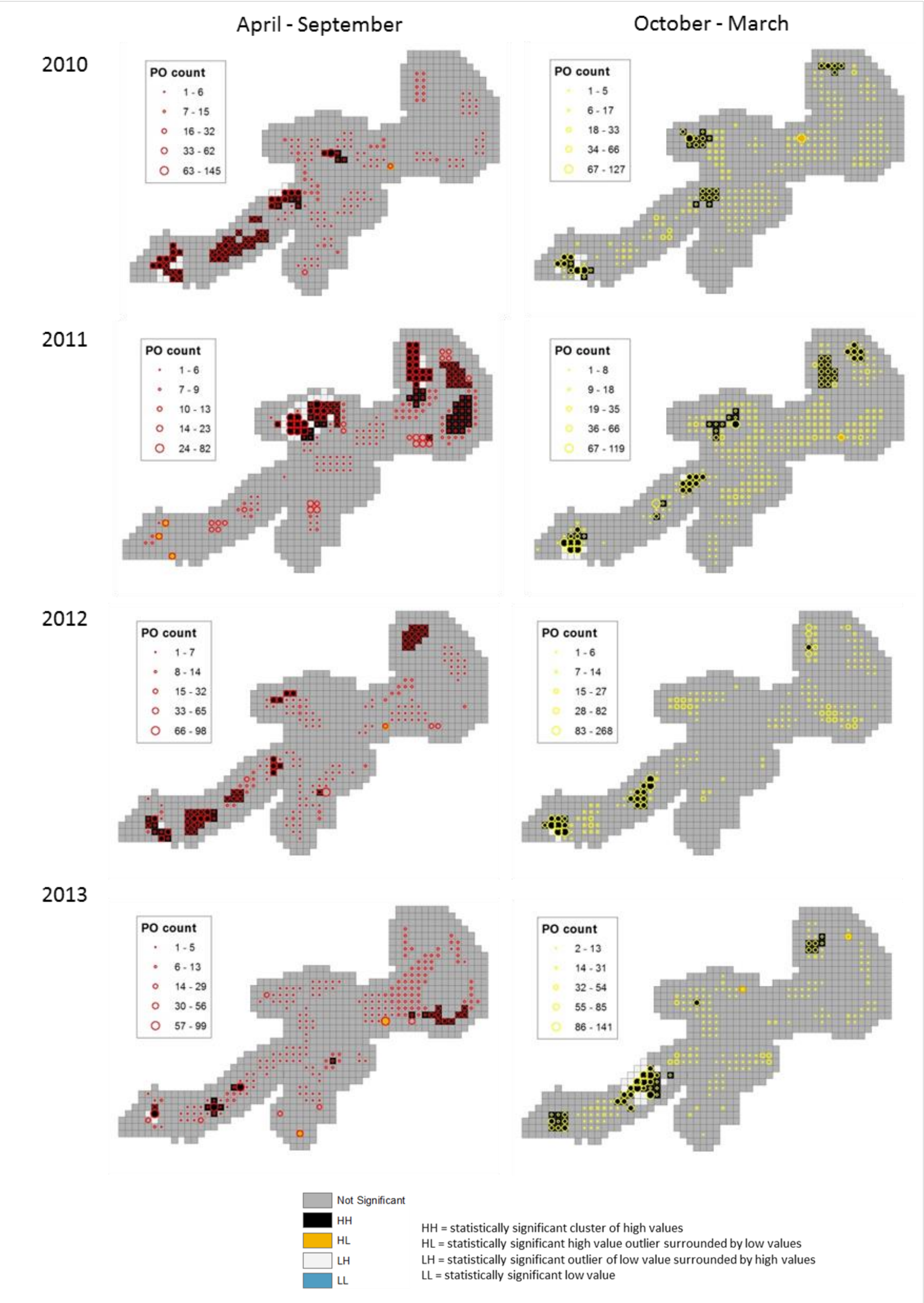


Figure 4.26 Spatial distribution of aggregated months (April- September and October-March) and Anselin Local Moran's I map output for Pochard during construction (2010 – 2013). The Western section, Hide Bay and areas to the north-west of the Main Section (by the main dam), were consistently occupied and for the majority of years, aggregations were also present within the Central Section.

4.3.3.19 Comparison of Pochard distribution pre and during construction

Although differences in Pochard distribution were observed (Figure 4.27), they are non-significant between the two study periods (years pre-construction compared with years during construction).

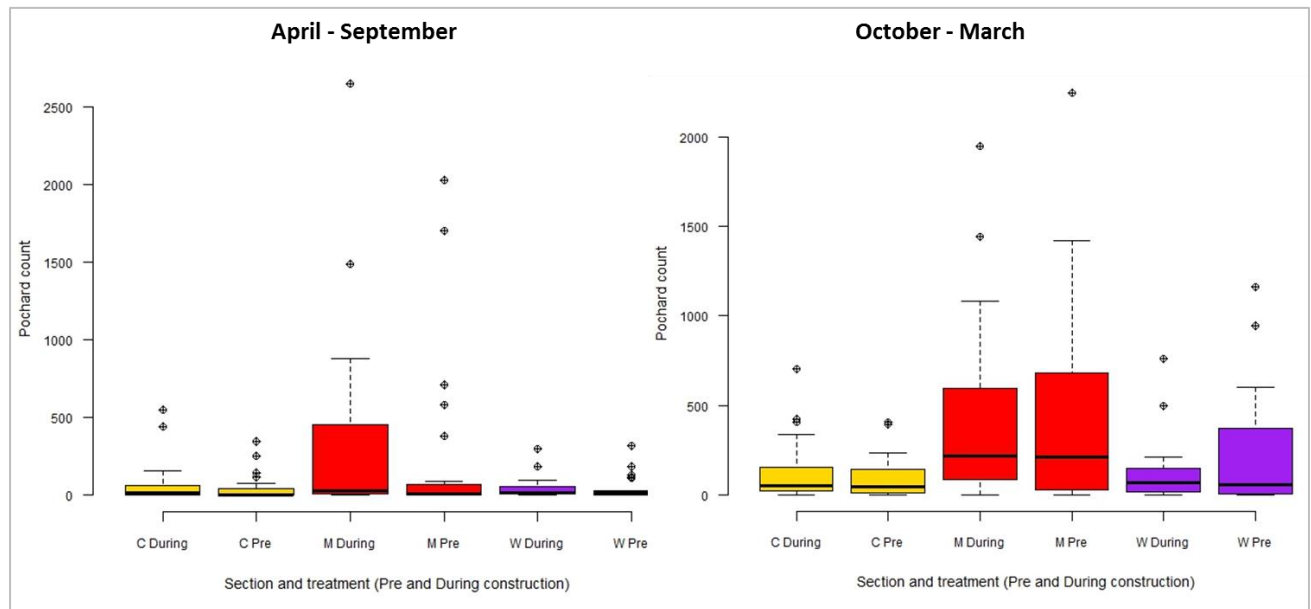


Figure 4.27: Comparison of Pochard distribution pre and during construction during April – September and October – March across Abberton Reservoir (Main (M), Central (C) and Western (W) sections).

Key findings for Pochard

1. No statistically significant differences in numbers of Pochard using Abberton Reservoir pre-construction compared with during construction observed.
2. During construction this species was largely absent from Wigborough Bay.
3. The only consistent pattern of spatial distribution was found for the Western Section.

4.3.3.20 Distribution of Mute Swan distribution pre-construction

Over the four years prior to construction activity, Mute Swan distributions exhibited spatial autocorrelation and were not randomly distributed across Abberton Reservoir. In all four years (2006-2009) the majority of Abberton Reservoir was classified as having non-significant clustering. Ripleys K-Function identified that significant clustering for this species was most pronounced

between 200m and 500m (the distance from cluster to cluster). Outputs of Anselin Local Moran's I cluster and outlier analysis and Mute Swan distribution across Abberton Reservoir are shown in figure 4.28.

In all four years pre-construction, the Western Section during the spring/summer consistently held significant aggregations of Mute Swan. During 2006 and 2008, the Western Section along with Wigborough Bay were preferred locations. The Central Section during 2007 and 2009, although only the eastern side in the former, also supported dense clusters of Mute Swan along with an area south of Hide Bay.

During October through to March, Mute Swan congregated in dense clusters with many distributions classified as significant. The Western Section was consistently occupied although in comparison to the other years and with Hide Bay, the area was not favoured during 2008. During 2007, with the exception of small pockets of significant clusters located on the northern shoreline of the Main Section, Mute Swans were principally located within the Central and Western Section (Figure 4.28).

4.3.3.21 Distribution of Mute Swan distribution during construction

Over the four years during construction there was spatial autocorrelation in the distribution of Mute Swan with the majority of Abberton Reservoir classified as having non-significant clustering which was most pronounced between clusters at distances of 200m and 500m. Figure 4.29 shows Mute Swan distribution and the outputs of Anselin Local Moran's I cluster and outlier analysis for years during construction.

Distribution for this species for months April through to September during construction completely differ compared with years pre-construction. Aside from 2010, there were no significant high clusters of Mute Swan within the Western Section and only a limited amount identified within the Central Section, whereas in years pre-construction, both of these sections were significant. The areas of Wigborough Bay and particularly Hide Bay during April to September held substantial significant

aggregations of Mute Swan, especially during years 2011 and 2012. These HH cells were also surrounded by areas lacking birds (LH cells) suggesting that clustering was intense.

During October through to March, distribution across the reservoir in terms of numbers and spatial extent was reduced compared with the summer period. With the exception of 2011 when the majority of Mute Swan were located within the Central Section, clustering was mostly confined to the Western Section (Figure 4.29). During 2012, no significant clusters were present within the Main Section and only areas of Wigborough Bay, Hide Bay and the middle of the eastern part of the Main Section contained significant clusters in any other year.

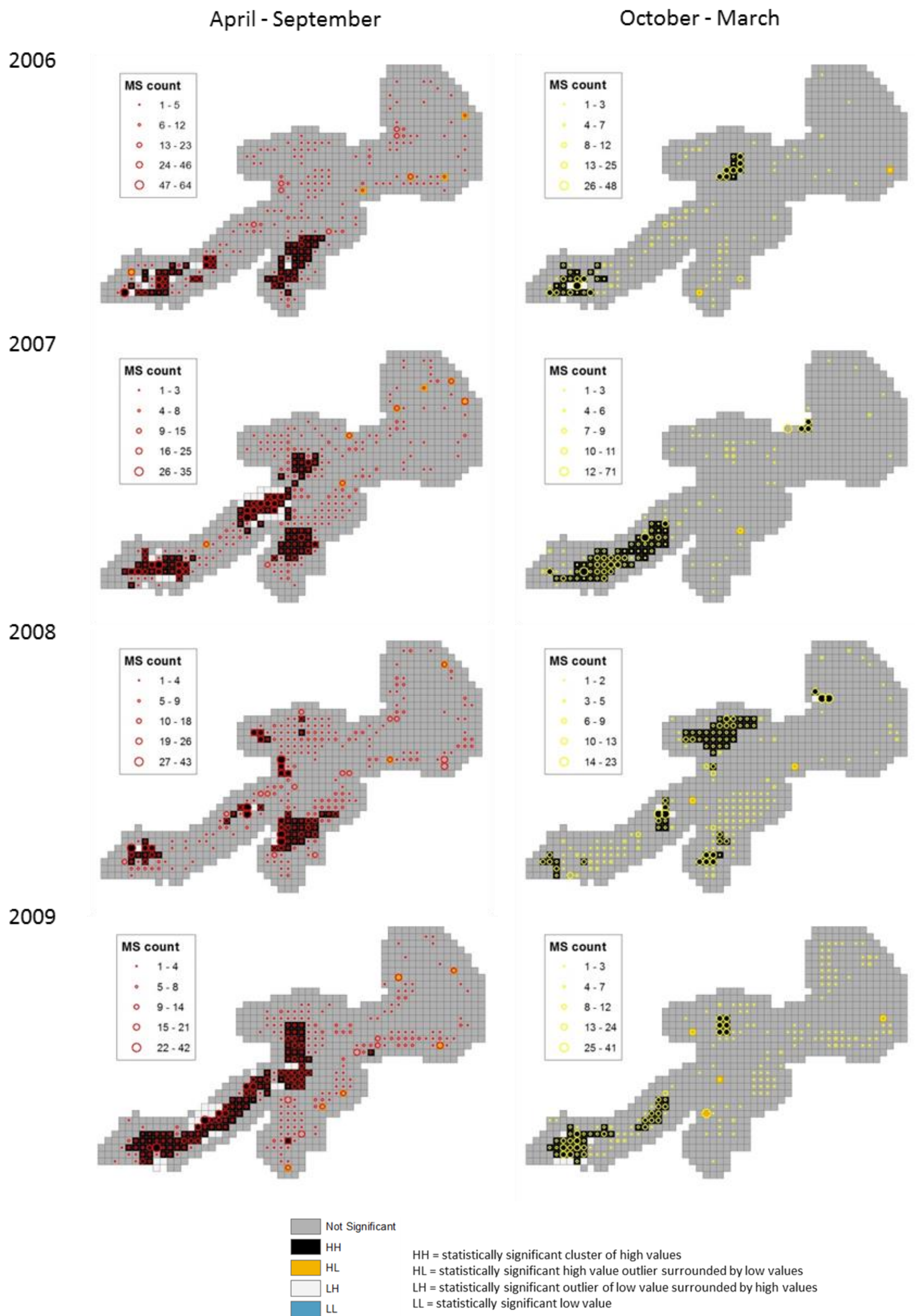


Figure 4.28 Spatial distribution of aggregated months (April- September and October-March) and Anselin Local Moran's I map output for Mute Swan pre-construction (2006 – 2009). During April-September, aggregations of Mute Swan were distributed throughout the reservoir with a preference shown for the Western section and Hide Bay. This pattern was also observed during the autumn/winter months although overall, fewer dense clusters were present.

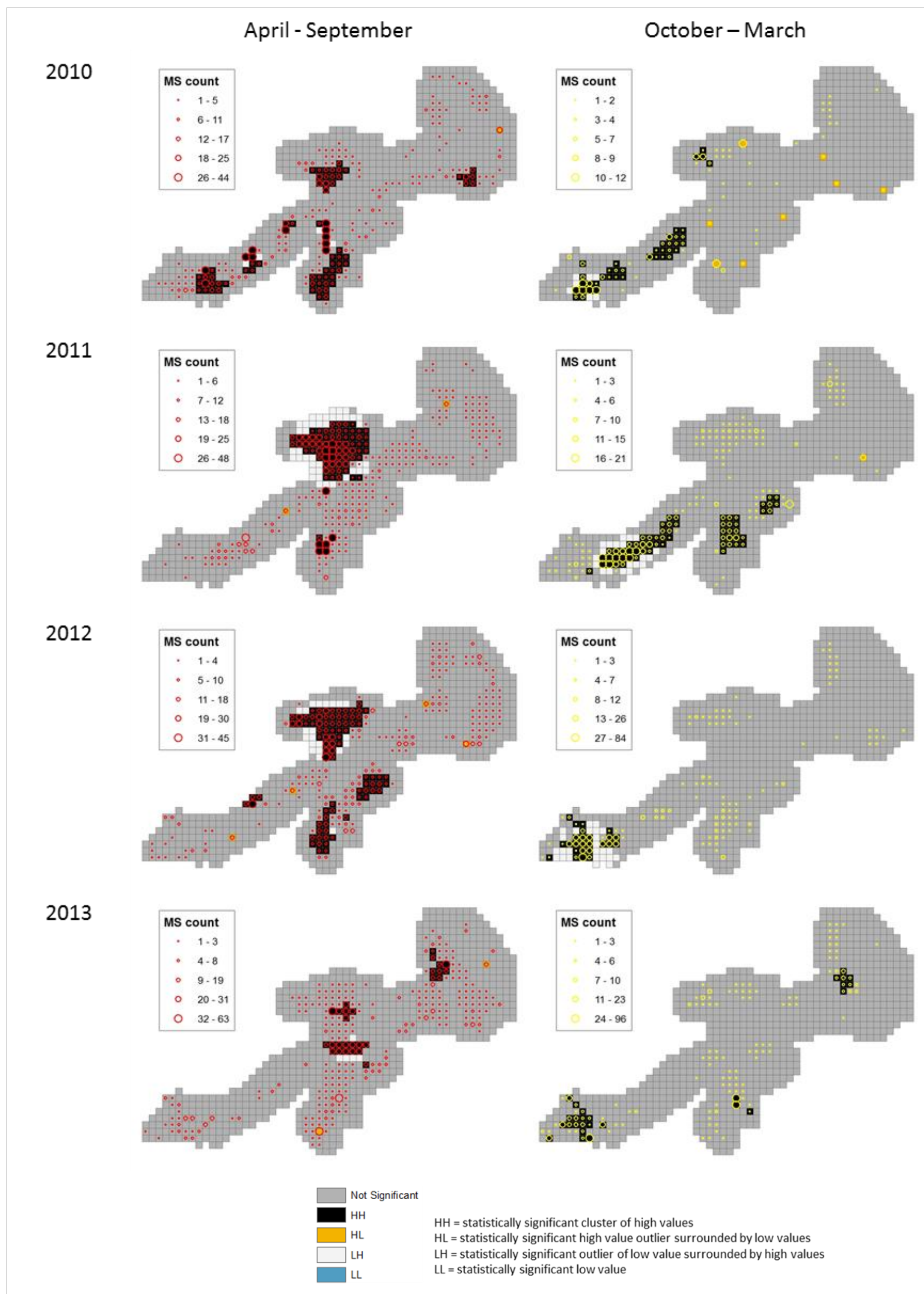


Figure 4.29 Spatial distribution of aggregated months (April- September and October-March) and Anselin Local Moran's I map output for Mute Swan during construction (2010 – 2013). In contrast to years pre-construction, the Western Section during April-September lacked dense aggregations of Mute Swan. During the autumn/winter months however, this section retained its importance and along with the Central Section, contained the majority of this species.

4.3.3.22 Comparison of Mute Swan distribution pre and during construction

The only significant difference between Mute Swan distributions was found within the Western Section for the combined months of April to September (Figure 4.30). Within this section Mute Swan were significantly higher pre-construction (Median pre-construction = 28.5, during construction = 10, Mann Whitney $U_{506.5}$, $p = < 0.001$).

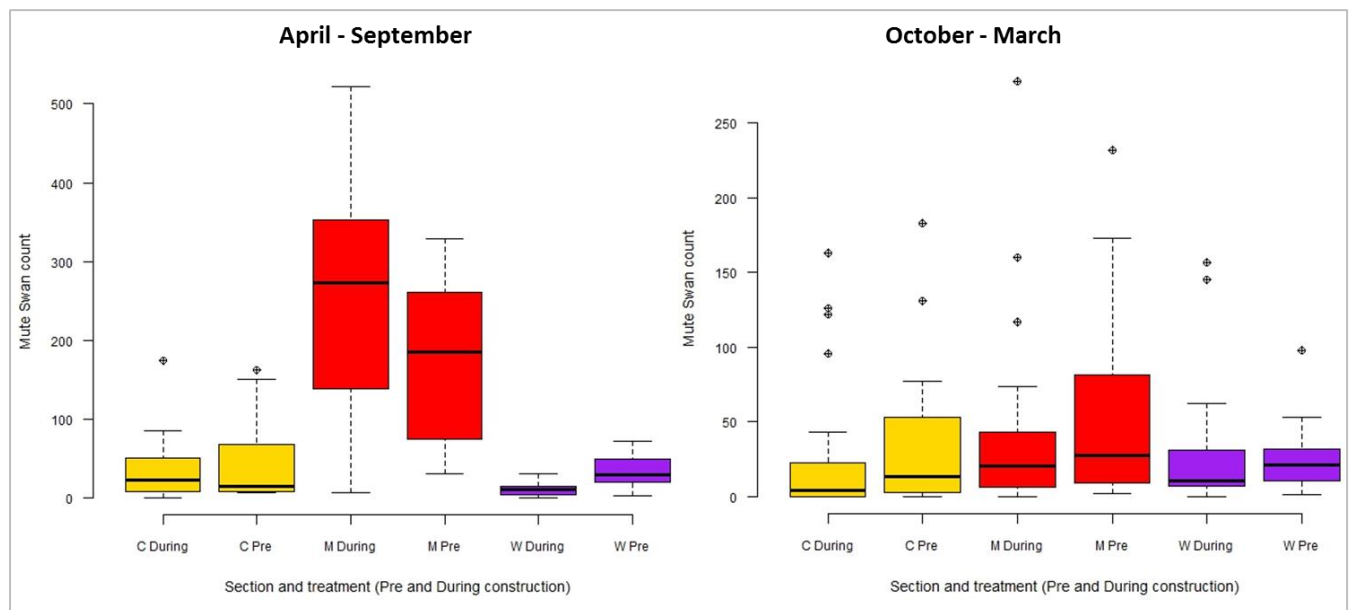


Figure 4.30: Comparison of Mute Swan distribution pre and during construction during April – September and October – March across Abberton Reservoir (Main (M), Central (C) and Western (W) sections).

Key findings for Mute Swan

1. Higher numbers of Mute Swan are observed for months April - September as compared to October – March.
2. Dense clusters were found within the Western Section, the Central Section and Hide Bay.
3. The only significant difference was found for the combined spring and summer months where this species was present in significantly higher numbers in the Western Section pre-construction compared with during construction.

4.3.3.23 Distribution of Great Crested Grebe pre-construction

Great Crested Grebe exhibited spatial autocorrelation in years prior to construction activity. In all four years the majority of Abberton Reservoir was classified as having non-significant clustering which was most pronounced between clusters at distances of 300m and 500m. Outputs of Anselin Local Moran's I cluster and outlier analysis and Great Crested Grebe distribution across Abberton Reservoir are shown in Figure 4.31.

For months April through to September, significant HH clusters were present within both the Main and Western Sections but none within the Central Section. During 2006 and 2009, the area of Wigborough Bay was important to this species although during 2009, significant clusters were further away from the shoreline and surrounded by cells containing significant low clusters.

During October through to March, Great Crested Grebe appeared to congregate in dense clusters with many distributions classified as significant, particularly during 2009 (Figure 4.31). For the most part, during these months there was an absence of this species from the Central and Western Sections with favoured areas similar to the other analysed SPA species. Unlike other species however, Great Crested Grebes were also present in the middle, narrower section of the Main Section with significant dense clusters occurring during 2009.

4.3.3.21 Distribution of Great Crested Grebe during construction

Over the four years during construction there was autocorrelation in the spatial distribution of Great Crested Grebe. Spatial dependence in Great Crested Grebes according to Ripley's K-Function was significant between distances of 200m and 500m and most pronounced between clusters at 300m. Figure 4.32 shows Great Crested Grebe distribution and the outputs of Anselin Local Moran's I cluster and outlier analysis for years during construction.

The spatial distribution for months April - September was similar to years pre-construction in that (excluding 2012), a preference was shown for the Main and Western Sections. The areas of Hide Bay and to the north-east of the Main Section were important however with the exception of 2013, the species was present (albeit in varying densities) throughout the Main Section.

During October through to March, cluster analysis for 2013 differs from that of other years with the majority of the north-east area of the Main Section containing significant aggregations covering a large spatial extent (Figure 4.32). This is even more significant due to the surrounding low value cells and the presence of cold spots in Wigborough Bay which in years pre-construction and up to 2012, was a preferred area. Cold spots are also present for 2011 and are located within Hide Bay and the outer parts of Wigborough Bay. For this year and during 2010, Great Crested Grebes were evenly distributed within the remaining parts of the Main Section.

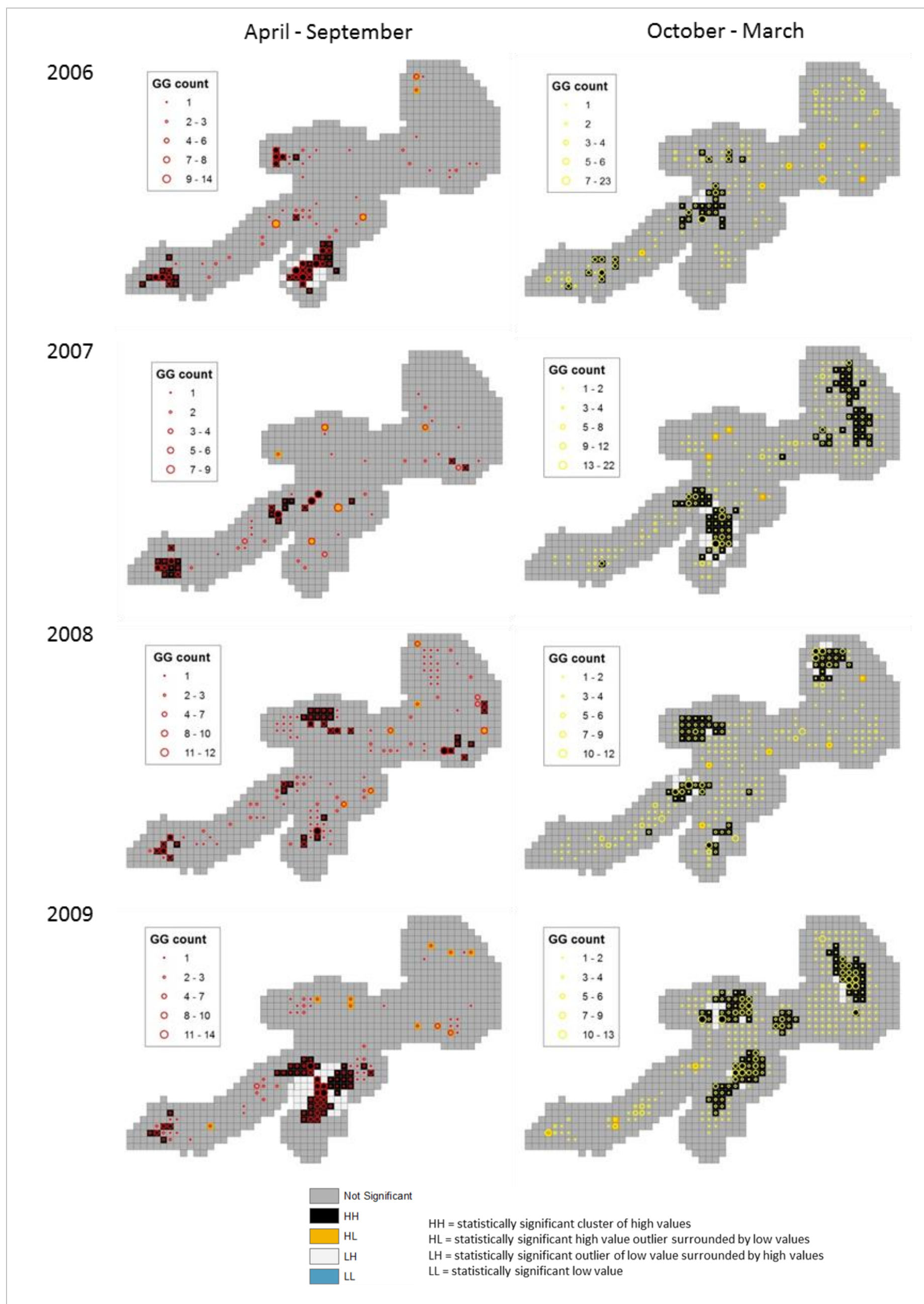


Figure 4.31 Spatial distribution of aggregated months (April- September and October-March) and Anselin Local Moran's I map output for Great Crested Grebe pre-construction (2006 – 2009). The Main Section contained the majority of significant aggregations across both temporal periods although during spring/summer, the Western Section held some significant clusters.

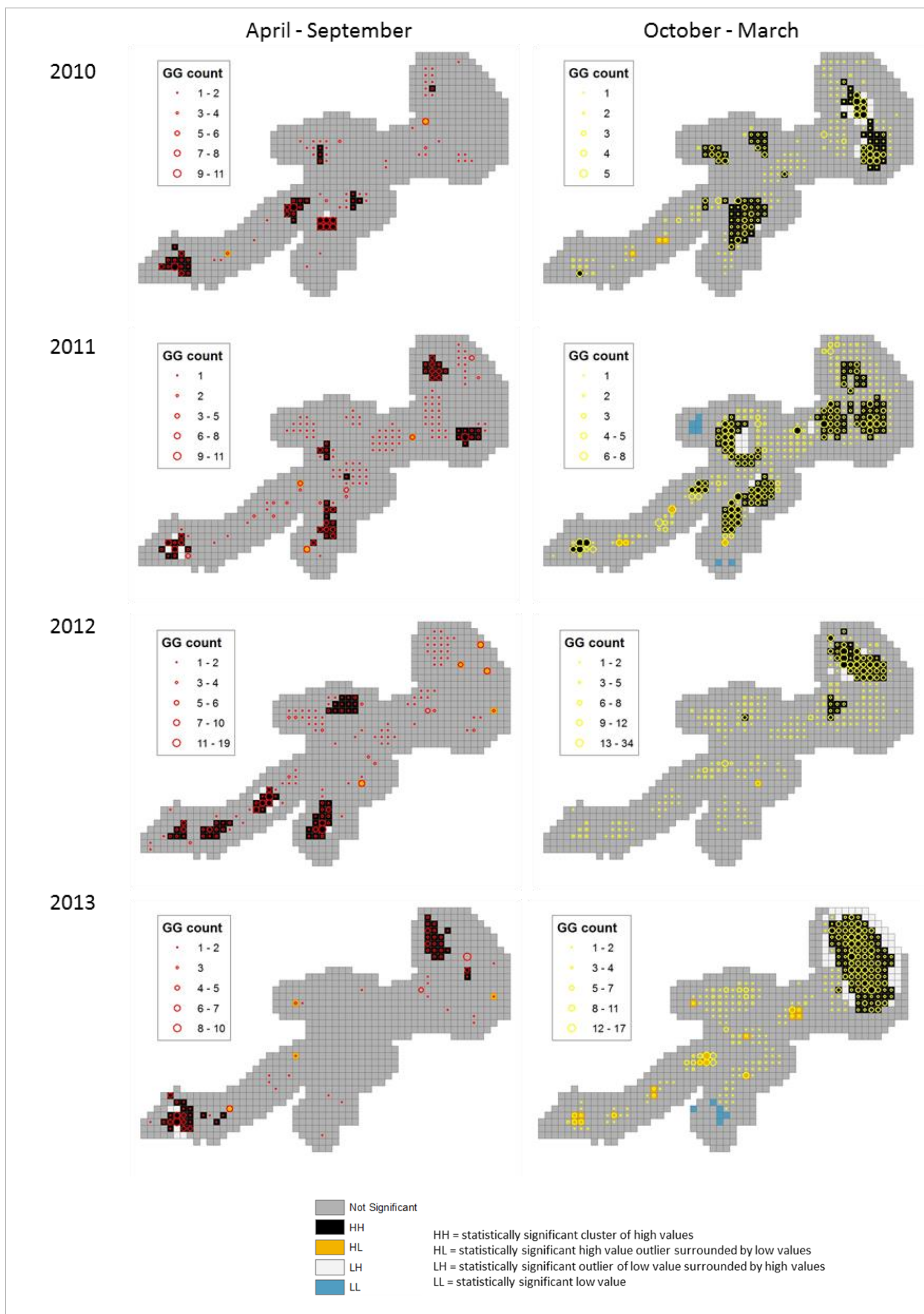


Figure 4.32 Spatial distribution of aggregated months (April- September and October-March) and Anselin Local Moran's I map output for Great Crested Grebe during construction (2010 – 2013). For the autumn/winter months, the northern areas of the Main Section contained large dense significant aggregations of this species and the number of occupied Refgrid cells increased compared to pre-construction.

4.3.3.25 Comparison of Great Crested Grebe distribution pre and during construction

The only significant difference between Great Crested Grebe distributions during construction compared with pre-construction (Figure 4.33) was found within the Western Section for the combined months of April to September. Within this section, distributions were significantly higher during construction (Median pre-construction = 2, during construction 5, Mann Whitney U_{197} , $p = 0.05$).

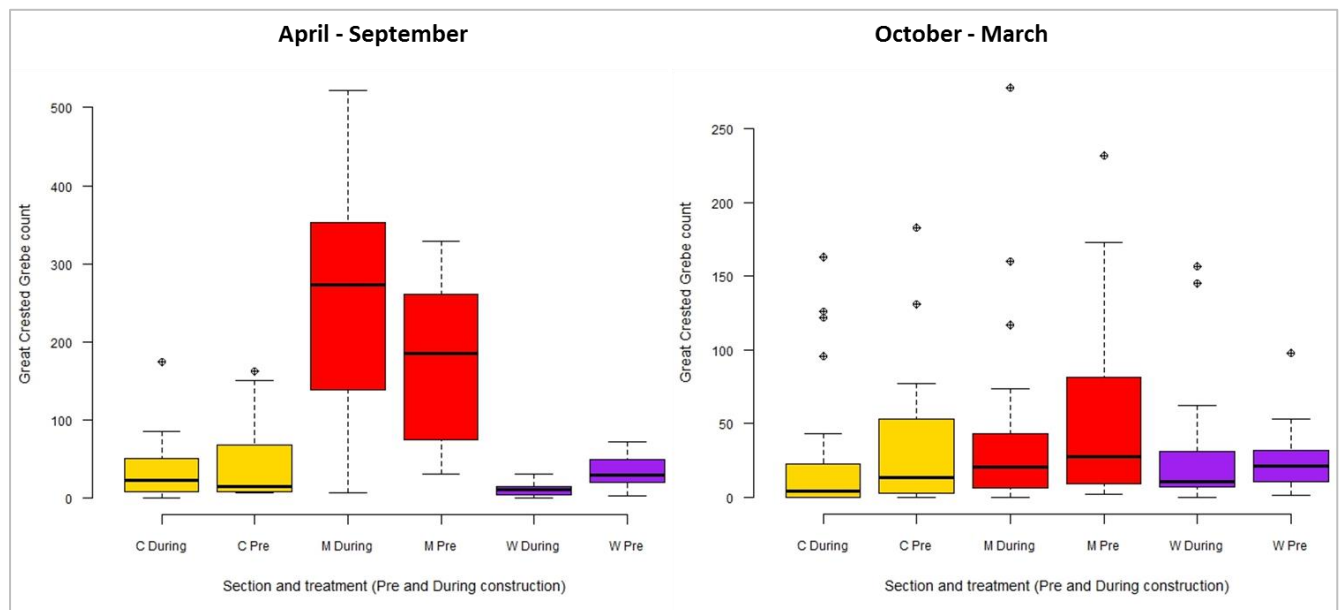


Figure 4.33: Comparison of Great Crested Grebe distribution pre and during construction during April – September and October – March across Abberton Reservoir (Main (M), Central (C) and Western (W) sections).

Key findings for Great Crested Grebe

1. Significantly higher numbers of Great Crested Grebe were observed during the spring and summer months at the Western Section in years during construction compared to years pre-construction.
2. This species was largely absent from the Central Section and showed a preference for the Western and Main Sections.
3. Wigborough Bay and the north east regions of the Main Section were favoured in the autumn and winter months, the latter particularly during 2013.

4.3.3.26 Species summary

Results show that the spatial distribution of nine Abberton Reservoir SPA species throughout the study period was variable. Differences are reported for years during construction (2010 – 2013) compared with years pre-construction (2006 – 2009), between April – September and October – March and within each of the three sections of the reservoir. A summary of significant results reported for each species, location and temporal time period is shown in Figure 4.4.

Table 4.4: Summary of significant results for nine Abberton Reservoir SPA species as presented in Chapter 4. Arrow indicates direction of change in waterfowl numbers during construction compared with year's pre construction.

Common name	Species (L)	Feeding guild	Temporal period	Entire site (all three sections)	Main Section	Central Section	Western Section
Shoveler	<i>Anas clypeata</i>	Dabbler	April – September	↑	No change	↑	No change
			October – March	No change	No change	No change	↑
Teal	<i>Anas crecca</i>	Dabbler	April – September	↑	No change	↑	No change
			October – March	↑	↑	No change	No change
Gadwall	<i>Anas strepera</i>	Dabbler	April – September	No change	↑	No change	No change
			October – March	↓	No change	↓	No change
Wigeon	<i>Anas penelope</i>	Dabbler	April – September	↑	↑	No change	No change
			October – March	No change	No change	↓	↓
Pochard	<i>Aythya ferina</i>	Diver	April – September	No change	No change	No change	No change
			October – March	No change	No change	No change	No change
Tufted Duck	<i>Aythya fuligula</i>	Diver	April – September	No change	No change	No change	No change
			October – March	↓	No change	↓	No change

Mute Swan	<i>Cygnus olor</i>	Grazer	April – September	No change	No change	No change	
			October – March	No change	No change	No change	No change
Coot	<i>Fulica atra</i>	Diver	April – September	No change		No change	No change
			October – March	No change	No change		No change
Great Crested Grebe	<i>Podiceps cristatus</i>	Piscivore	April – September	No change	No change	No change	
			October – March	No change	No change	No change	No change

4.4 Discussion

4.4.1 Use of Abberton Reservoir by SPA waterfowl aggregations

Reflected by its conservation designations, Abberton Reservoir is of principle importance for non-breeding waterbirds in the UK. Numbers are highest during the autumn and winter months corresponding with the annual migration where birds move in a southerly direction in response to colder climatic conditions at their breeding grounds. In years pre-construction (2006 – 2009), waterfowl numbers at Abberton Reservoir (all SPA species combined) peaked during October 2008 with 33,591 birds, whilst in years during construction, numbers were highest during October of 2011 (28,019 birds). However, this difference was not statistically significant; likely due to the variability in peak monthly counts across the eight years and because all three sections of Abberton Reservoir were considered cumulatively.

Whilst Abberton Reservoir essentially functions as one large wetland habitat, the use of each section varies and is noteworthy, particularly with regards to the size and relative use of each section. The Main Section represents by far the largest extent of habitat and, somewhat predictably, supports the highest numbers of waterfowl during the peak months across both study periods (pre and during construction). Use of the Central and Western Sections by Abberton Reservoir SPA waterfowl was especially variable in years during construction with the Western Section in particular, supporting less waterfowl, especially compared to the Main Section.

Numbers of SPA waterfowl on the Main Section were significantly higher during construction compared with pre-construction and peaked during 2011; coinciding with high counts recorded at other principal sites (Frost et al., 2016). During 2011 at Abberton Reservoir, the Main and Central Sections were hydrologically separated from one another and numbers of waterfowl were lower within both the Central and Western Sections compared with the Main Section. As a result of the hydrological separation and due to requirements for certain construction activities, water levels

within the Central Section during 2011 were lowered, potentially affecting food availability and increasing resource competition. The increase observed for the Main Section during this year coincides with removal of the concrete edge and profiling of the shorelines and is likely due to the resulting increase in available shoreline habitat. Additionally, whilst the Main Section is cited as being the only section subject to construction activity, the causeway road (B1026) separating the Main and Central Sections was raised as part of construction works. Impacts of construction disturbance associated with raising the B1026 causeway, along with the effect of water level is considered in subsequent chapters.

4.4.2 Use of Abberton Reservoir by SPA waterfowl species

4.4.2.1 Gadwall

This study has found that during the spring and summer months prior to construction (here regarded as April to September 2006-2009), the majority of Gadwall were located at the Western Section with very few significant clusters observed for the other two sections. Patterns for the same months were however different during construction (years 2010-2013), with significantly more Gadwall using the Main Section when compared to years pre-construction. This suggests that during construction, the Main Section was more favourable than the Central and Western Sections and likely represents a response by this dabbling species to the increase in shoreline habitat.

Despite an increase in use of the Main Section during construction for the summer months, a significant decline in total site use (all three sections considered together) and for the Central Section occurred during construction for months October - March. These months represent the overwintering period and are when numbers of waterfowl substantially increase at Abberton Reservoir and within the UK (Musgrove et al., 2011). The general trend for overwintering Gadwall across Britain has been one of steady increase and the count at Abberton Reservoir during January 2006, was particularly high (1024 birds recorded). Between 2007 and 2010, peak counts at Abberton

Reservoir were relatively stable until winter 2011/2012, when numbers again reached a record figure; a peak that was also reflected in national numbers (Austin et al., 2014b). The following winter of 2012/2013 saw a sharp decline in Gadwall at Abberton Reservoir (Appendix 4.4). However, this was not in isolation as significant declines were also seen at other sites such as Rutland Water, Britain's most important site for this species (Holt et al., 2012). The low numbers observed at Abberton Reservoir during 2011, combined with the exceptionally high count in 2006, may explain the significant decline found by this study; especially considering the general trend as reported by the Wetland Bird Survey (WeBS) is one of increase which is somewhat conflicting with findings reported by this study. In addition, although WeBS data are of immense value to bird conservation and accurately show the long term and site trends, analysis here includes monthly counts throughout the year. Findings reported are suggestive of increased variation in the spatial distribution of Gadwall at Abberton Reservoir during the construction period, and may represent a response to environmental conditions or construction disturbance.

4.4.2.2 Shoveler

Throughout the study period (2006 - 2010), Shoveler were found to have a clustered distribution, showing a preference for the shallow water areas of the Main Section known as Wigborough Bay and Hide bay (see Chapter 2: Section 2.6 for a site map). The north-east areas of the Main Section were largely absent of clusters with any significant aggregations situated to the west of the main dam. This westerly area benefits from a tree line which potentially offers a more sheltered location within this part of the reservoir, which is often subjected to harsh north easterly winds. In addition to prevailing wind conditions and with the exception of the shelter belt, water in this part of the reservoir along with areas by the causeway and the central belt of the Main Section is the deepest and food resources are likely to be more limiting for this species.

Similarly to Gadwall, this dabbling species also formed significant clusters within the Western and Central Sections; the latter holding significantly more Shoveler during construction in months April -

September compared with years pre-construction. For these spring/summer months, Shoveler also significantly increased during the construction period when Abberton was considered as a wetland in totality (i.e. all sections combined). For the over winter period of October through to March, there was a significant increase in Shoveler using the Western Section during construction compared with pre-construction and although non-significant, an increase was also found for the Main Section.

The general British trend over the past 15 years for Shoveler has been one of increase although this has only been observed at Abberton Reservoir since winter 2010/2011, corresponding with the changes to Abberton Reservoir as a result of the Abberton Scheme. This may be a coincidence; however the increase seen at Abberton Reservoir has been extraordinary (Appendix 4.4), with Abberton Reservoir now being the top site in England for this species (Frost et al., 2016). The increase at Abberton Reservoir has been year on year and was also observed during the relatively cold winters of 2010/2011 and 2011/2012. During these colder periods, the national index of Shoveler across England fell and was thought to be due to the frozen conditions affecting feeding areas (Holt et al., 2012). The significant increase during construction across the winter months at Abberton Reservoir was seen at the Western Section which was enhanced by the creation of shallow water scrapes during autumn 2008. This extra habitat was created as an onsite refuge for waterfowl that may be displaced from the Main Section as a result of construction activity. A significant increase at the Western Section during winter, outside of the main construction period, together with a significant increase during construction across all sections for the summer months, suggests that whilst Shoveler were using this refuge in greater numbers than pre- construction, it may not necessarily be as a result of construction disturbance. This will be explored in subsequent chapters.

4.4.2.3 Teal

During the winter months (October – March), Teal in years pre-construction were mainly situated within the Central Section, particularly along the northern shoreline. 2009 was an exception and whilst significant clusters were seen within the Central Section, the majority were on the Main

Section within Hide Bay. During the winter of 2009, aggregations of Teal were also seen throughout the Main Section which in previous years only contained much smaller rafts of birds. This is perhaps indicative of a good year for overwintering teal within Britain and is supported by WeBS counts which showed an influx of this species in response to colder weather conditions on the continent (Holt et al., 2011).

The pattern of higher use for the Main Section continued across the years during construction where this dabbling species was well distributed throughout the shallower margins of the reservoir. The most significant aggregations were however, consistently seen in Hide and Wigborough Bay as well as within the north-west corner which was also favoured at certain times by Shoveler. Teal also showed a similar pattern to Shoveler for the combined months of April - September with significantly higher numbers using the Central Section during construction. This was not however observed for the winter months when numbers within this section decreased, albeit not significantly. For the combined months October - March, this study found a significant increase in numbers of Teal using the Main Section during construction and for both spring/summer and autumn/winter periods, increased numbers during construction compared with pre-construction (when all sections are considered together). The influx of Teal to the Main Section is a likely response to the new shallow shorelines created during 2010 and 2011 although this would not account for the significant increase seen during the spring/summer months for the Central Section. Annual numbers of Teal visiting Britain naturally fluctuate and are thought to be a result of cold weather movements combined with the species sensitivity to water levels altering site attractiveness from year to year (Holt et al., 2009). Indeed, dabbling waterfowl have been shown to respond negatively to increasing water levels (Baschuk et al., 2012, Tavares et al., 2015) and investigating Teal distributions in response to water depth may explain some of the findings reported for Abberton Reservoir.

4.4.2.4 Wigeon

During the combined months of April – September and in years 2006 and 2009, Wigeon counts were comparatively low with significant clusters only observed for the Central and Western Sections. The distribution of Wigeon at Abberton Reservoir during 2007 and 2008 was much more typical with that of other dabbling species with large aggregations present near Hide and Wigborough Bay. During this time however, there was a notable lack of this species within the Western Section and those present within the other sections were aggregated in tight rafts, perhaps as moulting or roosting flocks. During construction, numbers of Wigeon were significantly higher within the Main Section, with a significant increase also found when all three sections were combined to represent Abberton Reservoir as a total wetland site; a pattern which has also been shown for Shoveler and Teal.

During autumn/winter in years pre-construction, numbers of Wigeon increased compared with the spring/summer months and were more dispersed throughout the reservoir. Peak counts during winter 2006/2007 were the lowest recorded at Abberton Reservoir and were in contrast with the previous winter which saw a record peak count of almost 14,000. Whilst this count for Abberton Reservoir was particularly high, the British index did also rise to its highest level (Musgrove et al., 2007), reflecting particularly favourable overwintering conditions within England at this time.

For the winter months during construction, the distribution of Wigeon was consistent with overwintering trends for the site though additional significant high clusters were observed for the Main Section. Preferred areas were typically located within Hide and Wigborough Bays and also to the north-west corner by the shelter belt of trees as with the other dabbling species. During winter of both 2012 and 2013, there was a distinct lack of Wigeon using the Central and Western Sections and an increase seen on the Main Section. This decline across the Western and Central Sections was significant when compared to years pre-construction and although the increase seen in the Main Section was non-significant, it is suggestive of improved conditions within the Main Section.

4.4.2.5 Coot

Abberton Reservoir is the most important site in the UK for this species and although numbers have fluctuated throughout the years, peak counts generally surpass that of any other site (Appendix 4.4). The principle exception was during winter of 2006/2007 where numbers dramatically reduced in comparison to other years; a decline which was also seen in national numbers (Austin et al., 2008). Spatial analysis of Coot distributions at Abberton Reservoir for these years, showed that during autumn/winter 2006, there were very few significant aggregations across the reservoir. However, those present were aggregated in very dense clusters, with numbers occupying certain 100m² cells reaching over 1000 individuals. Coot favour large bodies of fresh water and gather to moult in the early autumn which is reflected in the monthly indices for this species (Calbrade et al., 2010). Moulting and overwintering birds tend to aggregate together in dense flocks for safety and this behaviour may be exaggerated when populations within an area are low. Waterfowl do also aggregate for other reasons, including in response to environmental conditions such as food resources, wind and cold temperatures; the latter of which this species is thought to be particularly sensitive to.

Although numbers of Coot at Abberton Reservoir are highest over the autumn/winter period, they are present throughout the year. In years pre-construction and during the spring/summer months, the Western Section was important with significant clusters observed across all four years.

Consistent with other waterfowl species, Hide Bay within the Main Section was a favoured area and one which continued to be of importance throughout the construction period. One notable change for these months was the increase in Coot aggregations within the Main Section during construction compared with years pre-construction. Similar to other species, this increase is likely to be a result of the enhancements to the Main Section. Coot is a species that bred in limited numbers at Abberton Reservoir prior to construction and it is possible that this increase is also linked to enhanced breeding opportunities within the Main Section as a result of removal of the concrete edge. This is

supported by fieldwork which reported an increase in nesting behaviour following shoreline re-profiling. The other notable difference for the spring/summer-months was the lack of Coot within the Central Section, particularly during 2012 and 2013. Numbers were also reduced within this section in years 2006 and 2009 which may be linked to water levels; the effect of which will be investigated in subsequent chapters.

Over the autumn/winter period in all years, the Main and Central Sections held most of the significant aggregations with the Western Section appearing less important. In years during construction, spatial analysis revealed cold spots i.e. there were 100m² cells that contained significantly less birds compared with surrounding cells. This pattern was particularly evident for the Western Section during 2011, and may have been due to the cold and icy conditions during this winter, resulting in large parts of this relatively small section freezing over. The other main difference occurring between the two study periods for this species was the use of the Central Section in which there were significantly less Coot during construction compared with pre-construction. The lack of Coot within this section is especially evident during 2011 and 2013 which may be linked to construction activities associated with the causeway raising and a general shift in this species toward the Main Section.

4.4.2.6 Tufted Duck

This species showed the same decline at Abberton Reservoir during the winter of 2006/2007 as was observed for Coot, however, it appears to be more site specific since Hanningfield Reservoir and the Ouse Washes reported higher than average peaks during the same winter (Austin et al., 2008). In addition, Tufted Duck populations have been fairly stable across Britain and indexes for this winter only showed slight variation from the long term trend. In contrast with the low peak for 2006, counts at Abberton Reservoir during winter of 2009 were particularly high with a preference observed for Hide Bay and along the sheltered shoreline of the north-west corner of the Main Section. During this autumn/winter, the Western Section was notably absent of any significant aggregations with some

100m² cells even highlighted as cold spots. Whilst the Western Section did hold some aggregations of Tufted Duck, it is not a preferred location for the autumn/winter period as evidenced by the relatively low numbers using the area across all years.

Throughout the eight years, the Central Section appeared to hold consistent aggregations of Tufted Duck. However, when comparing count numbers this study found significantly less birds using this section during construction as compared with pre-construction. Significantly less Tufted Duck were also present throughout the reservoir (counts for all three sections combined), during construction compared with years 2006 – 2009. The reasons for these significant declines at Abberton Reservoir are unknown but may be linked to low counts recorded during the cold winter of 2010/2011 and also construction activity affecting the distribution at this site. Declines in this species as well as other diving duck species has been attributed to climate change, particularly in northern Europe where a shift has been observed in response to changes in temperature (Nilsson, 2008, Lehtikainen et al., 2013). However as yet, any effect on Tufted Duck has not been strongly detected in Britain so it would appear the decline at Abberton Reservoir is for the most part, site specific.

4.4.2.7 Pochard

Numbers of Pochard wintering in Britain have halved over the last 25 years (WeBS trend) and following the fourth review on the status of birds in the UK, Channel Islands and Isle of Man they are one of 20 species that have added to the red list (Eaton et al., 2015). Despite the national decline, this study found no significant difference in numbers of Pochard at Abberton Reservoir across the eight year study period. It is likely that this is due to the steady long term decline, the full extent of which may not be apparent in the comparatively short period upon which this study is based. In addition, numbers of Pochard at Abberton Reservoir have fluctuated across the eight years with peak counts lowest during the winters of 2008/2009 and also in 2012/2013 the latter of which also saw declines in other Abberton Reservoir diving species such as Tufted Duck and Coot. It is thought the overall decline seen for Pochard - which is the UK's fastest declining duck species is due to subtle

shifts in core wintering range in response to milder winters (Calbrade et al., 2010). The decline during 2008/2009 coincided with low counts across Britain, with those at Abberton Reservoir some of the lowest recorded for the site. The decline over winter in 2012/2013 was more severe at Abberton Reservoir than at other key sites with some such as the Ouse Washes recording relatively high numbers (Appendix 4.4). The decline at Abberton Reservoir therefore is likely attributed to a reduction in habitat suitability or reflects a disturbance response and requires further investigation.

Distributions of Pochard at Abberton Reservoir were found to be consistently present within the Western Section where they were densely aggregated. It is likely that these aggregations were roosting flocks as Pochard show a preference for open water surrounded by belts of tall, fringing aquatic vegetation which offers shelter and protection from predators (Cramp and Simmons, 1977). The only other notable spatial pattern observed for Pochard occurred throughout the construction period and was an avoidance of Wigborough Bay; an area largely favoured by other waterfowl species. It is likely that this is due to the presence of relatively shallow water which may not be favourable for deeper diving species such as the Pochard. This does not however explain use of this area in years prior to construction and may therefore also represent a shift in distribution as a result of other habitat changes.

4.4.2.8 Mute Swan

The Mute Swan is a long lived species with populations in Britain and Ireland considered sedentary, comprising discrete populations both from one another and from birds on the continent (Rowell and Spray, 2004). Consequently all sites of national importance in Britain and Ireland are also classed as being of international importance (Frost et al., 2016). For this reason, following the review of the status of bird species in the UK, Channel Islands and Isle of Man the Mute Swan has been added to the Amber list of birds of conservation concern (Eaton et al., 2015).

Populations of Mute Swan have been relatively stable following an increase since the 1980's which has largely been attributed to a reduction in occurrences of lead poisoning which was shown to be the single largest cause of Mute Swan fatalities in the 1970s (Rowell and Spray, 2004). At Abberton Reservoir, populations of this species over the study period have also been relatively stable with numbers highest during the spring and summer months. It is likely that these birds largely consist of immature and non-breeding adults as well as some breeding pairs. The only significant difference in spatial and temporal distribution in this study found was at the Western Section for the spring/summer months, during which Mute Swan numbers were higher in years pre-construction. This decline coincides with an increase in birds using the Main Section, although the result was non-significant and the impact of increased mortality associated with power line strikes at this section should also be considered. Although an impact was observed, if fatal strikes did have a detrimental effect at a population scale then this study should have also found a significant decline in numbers generally present at Abberton Reservoir which was not observed.

4.4.2.8 Great Crested Grebe

Peak counts of Great Crested Grebe over the past eight years at Abberton Reservoir (Appendix 4.4) have been stable with a slight increase (non-significant) shown for years during construction. Nationally however, WeBS counts show that the UK's wintering population has declined by 25% over the last ten years and the maxima recorded at a number of key sites has fallen (Austin et al., 2014b). This decline follows a trend of prolonged growth since the population was drastically reduced in the latter half of the 19th century as a result of people's fondness for the bird's decorative plumage. At Abberton Reservoir, this study found numbers of Great Crested Grebes to be significantly higher at the Western Section over the spring/summer months in years during construction compared to years pre-construction. A slight increase was also seen during this time for the Main Section and although not statistically significant, is consistent with the general trend for the site. With the exception of 2012, Great Crested Grebes were largely absent from the Central Section across all

eight study years, indicating this area is not favourable for the species. This is likely due to the fluctuating water levels and the relatively turbid water, especially when compared with the Main Section, which outside of the breeding season is clearly preferred. Locations supporting high dense clusters of this species within the Main Section were (as with many other species), the sheltered bays. Preference was also shown for north-east area which is typically more exposed with deeper water. This species frequents coastal areas as well as inland water bodies and it may be that they are more tolerant of these exposed areas compared with other species. This area is also the location of the main water inlet for the reservoir which may attract fish upon which the grebes mainly feed.

4.5 Conclusions

Data collected in years prior to the construction of the Abberton Scheme (2006 – 2009) and in years during construction (2010 – 2013) has enabled the waterfowl distribution at Abberton Reservoir to be successfully and accurately mapped and analysed. Overall, results show that Abberton Reservoir SPA waterfowl populations (all nine species combined), increased within the Main Section in years during construction compared to the years pre- construction. This suggests any impact or displacement resulting from the construction phase did not detrimentally affect SPA waterfowl aggregations using the site. Whilst this was generally supported by the species analysis, differences were found which highlights the variation in species sensitivities, requirements and their use of the reservoir.

Overall, increases across the whole reservoir complex (all three sections combined) were found during construction for Shoveler, Teal and Wigeon for the months of April – September. Additionally, analysis found that for this time period, none of the nine analysed species significantly reduced in numbers. This is a significant finding given that the months of April – September was when the majority of construction activity occurred (2010 – 2013). Although the direct impact of disturbance is fundamental to this study, Abberton Reservoir is of international importance due to the numbers of waterfowl visiting over winter and as such analysing the effect of construction activity was extended to the autumn and winter months. During this time (October – March) numbers of Shoveler and Teal also increased however, a decline was found for Gadwall and Tufted Duck.

Analysis of the whole reservoir system provides a good indication of how the site fared across the eight year study period. However, it is important to acknowledge that the three sections of the reservoir are all used to differing degrees by species, both spatially and temporally. The Main Section representing 86% of the reservoir extent was subject to construction activity during 2010 and 2013. During this time, the spring/summer numbers of Gadwall, Wigeon and Coot using this section all

increased compared with the same months pre-construction. Over the autumn and winter months, no significant differences were found for any species and numbers of Teal increased; further supporting the view that disturbance on the Main Section did not detrimentally impact upon Abberton Reservoir SPA waterfowl. This was however, not found for the Central Section which showed considerable variation in terms of species use, although numbers of both Shoveler and Teal increased during years of construction activity; consistent with the overall increasing trend for these species at Abberton Reservoir.

Historically, the Western Section has always been important for waterfowl during the moulting period (Fox and King, 2011), and during 2008, the area available was expanded through the addition of shallow water scrapes. The aim of this habitat creation was to provide any displaced waterfowl with a safe refuge away from construction activity. However, an increase in use of this section during the construction period was only found for Great Crested Grebe. During the autumn and winter months, Shoveler also used the Western Section to a greater extent during construction although this result may be a reflection of the general increasing trend of this species using Abberton Reservoir. Use of the Western Section and displacement habitat creation is assessed in Chapter 6.

Despite the majority of SPA species showing significant increases in numbers during construction, some declines were observed. This was most apparent in overwintering numbers of Tufted Duck which declined significantly during the construction period, both across the site and within the Central section. The decline appears to be site specific, as national numbers, although subject to natural fluctuation, were relatively stable. Numbers of Coot, Gadwall and Wigeon also declined within the Central Section, which may be attributed to disturbance associated with the causeway raising; assessed in Chapter 5.

In conclusion, the spatial and temporal distributions of Abberton Reservoir SPA species have shown considerable variation over the past eight years. However, findings reported by this study are encouraging as they demonstrate that over the reservoir system as a whole, SPA waterfowl

populations were not detrimentally affected by construction of The Scheme. The majority of dabbling species increased within the Main Section, whilst other species did not respond so positively and declines were reported for both the Central and Western Sections. Findings presented here should be considered as a baseline for further assessment and environmental variables such as water depth and food availability should be assessed in parallel with construction disturbance in order to accurately determine the true effect of disturbance activities at this site. The effects of construction activity and the influence of environmental variables form the basis of the following chapter.

Chapter 5

Construction disturbance assessment

5.1. Introduction and aims

During the planning phase, ecological surveys were used to assess and predict potential impacts upon Abberton Reservoir SPA species as a result of construction of the Abberton Scheme. Part of the assessment was to design a programme of construction activity that minimised disturbance to waterfowl to such an extent that there would be no adverse effects upon the SPA features (the 11 SPA waterfowl species). These analyses are outlined in the Study To Inform an Appropriate Assessment (STIAA); a review of which is provided in Chapter 6: Section 6.3.

To determine if construction activity influenced the distribution of waterfowl during years 2010 - 2013, environmental factors influencing distribution across the reservoir in the absence of construction activity must be determined. Analysis of pre-construction data (years 2006 – 2009), provides a baseline understanding of the environmental factors affecting waterfowl distribution and was used to further assess the impacts of construction disturbance. Results from analysis of the baseline years are presented in Part A of this chapter.

Part B assesses the influence of environmental factors and construction activity during 2010 – 2013, which has been ranked and the locations and extent of construction activity mapped. Using a combination of spatial mapping and statistical analysis, results from Parts A and B are used to determine if construction activity at Abberton Reservoir resulted in any disturbance to the SPA waterfowl species.

For consistency, the same statistical methods and environmental variables were used for analysis in both parts. The months of April – September were used because the majority of construction activity occurred during this time; this was part of a phased programme design implemented to reduce potential disturbance impacts.

The aims of this chapter are to:

Part A

- Investigate the spatial patterns in nine Abberton Reservoir SPA species in the four years prior to construction activity (2006 – 2009).
- Assess the influence and importance of environmental variables on the nine SPA waterfowl species in the four years prior to construction activity (2006 – 2009).

Part B

- Investigate the spatial patterns in nine Abberton Reservoir SPA species in the four years during construction of the Abberton Scheme (2010 – 2013).
- Assess the influence and importance of environmental variables on waterfowl distribution during the construction phase (2010 – 2013) for nine Abberton Reservoir SPA species.
- Assess the impact of type and magnitude of construction activity disturbance on nine Abberton Reservoir SPA species.

5.2 Methods

5.2.1 Waterfowl data collection and analysis

Waterfowl data, collected each month throughout the study period (2006 – 2013) were organised and mapped in Esri ArcMap 10 (Chapter 3: Methods). For the purpose of construction disturbance, assessment waterfowl occurrence at the Western Section (mitigation habitat) was excluded from analyses for the following reasons:

- The Western Section was not subject to any construction activity with the nearest source of disturbance 1,400m away. Waterfowl using the Western Section are therefore highly unlikely to have been directly affected by construction activity.
- Two causeways separate the Western and Main sections; with construction only occurring around the Main Section and on the Main/Central causeway.
- The Western Section for the purpose of this study is considered as mitigation habitat; analyses of waterfowl use of the Western Section and the success of mitigation techniques are assessed in Chapter 6.

5.2.2 Construction disturbance assessment

5.2.2.1 Data collection and organisation

Data spanning four years (2010 – 2013) was collected as part of this research and assessed in order to quantify and map the extent of disturbance occurring each day of the monthly waterfowl surveys. Each 100m² Refgrid was assigned a disturbance category and magnitude level based on construction attributes and combined with species distributional data (Chapter 3). Spatial data for each species during the construction period was then compared with data from the pre-construction phase (2006

– 2009), and exported into Excel/CSV files for further analysis. With the exception of Moran's I, all statistical analyses were undertaken in R v 3.2.2 using the RStudio interface (R Core, 2015).

5.2.2.2 Spatial analysis - Moran's I

Previous analysis (Chapter 4) of aggregated waterfowl data over months April – September showed those species which exhibit spatial autocorrelation/clustering. In order to further assess the impact of construction disturbance on waterfowl, data were assessed each month and a Moran's statistic calculated in ArcGIS (Esri ArcMap 10). Moran's I measures spatial autocorrelation based on feature locations and attribute values using the Global Moran's I statistic. If spatial clustering is observed, the Moran's index value is positive and if the spatial pattern is random, a negative value is observed. Results were used to determine the extent and trend of spatial clustering exhibited for each species per month and assisted in determining further analysis.

5.2.2.3 Statistical analysis - covariate assessment

All available environmental variables/covariates (Chapter 3), along with species count data and construction variables were assessed for collinearity (existence of correlation between covariates) using panel plots, variation inflation factor (VIF) and correlation tests. Panel plots allow visual assessment and VIF provides an assessment of linear dependencies and measures the proportion by which the variance of a regression coefficient is inflated in the presence of other explanatory variables; a VIF value above 10 suggests potential collinearity (Montaño-Centellas and Garitano-Zavala, 2015). As recommended by (Zuur et al., 2009), variables with a VIF above 3 indicate some collinearity and were therefore removed from subsequent analysis. As a result of the data exploration phase (Chapter 3) several variables were dropped from further analysis. A summary of the covariates assessed for analysis is provided in Table 5.1.

Table 5.1: All possible covariates considered for analysis, if they were included in subsequent analysis and reasons for exclusion.

Covariate name	Name (abbreviated in model)	Retained for statistical modelling	Reasons for exclusion
Year	Year	Yes	NA
Month	Month	No	Heterogeneity – unequal variances across the months
Day	Day	No	Too few replications of certain days/waterfowl
Section	Section	Yes	NA
Water depth	W.Depth	Yes	NA
% macrophyte cover	M.Pct	Yes	NA
Temperature	Temp	Yes	NA
Total rainfall	Total.Rainfall	Yes	NA
Wind speed	Windspd	Yes	NA
Wind direction	Winddir	No	Failure to converge with hurdle model
Wind high	Windhigh	No	Correlated with wind speed
Distance to shoreline	Dist.S	No	Correlated with construction variables i.e. DT1 and with % cells with disturbance
% cells with disturbance	CellsDist	No	Correlated with construction variables i.e. DT1 and with level of disturbance
Level of disturbance per day	Level_dist	No	Correlated with construction variables i.e. DT1
Distance to nearest disturbance event	NearDistCell	No	Correlated with construction variables i.e. DT1
Distance to nearest HIGH level TOTAL disturbance event	DTC1	Yes	NA
Distance to nearest MEDIUM level TOTAL disturbance event	DTC2	Yes	NA
Distance to nearest LOW level TOTAL disturbance event	DTC3	Yes	NA
Distance to nearest HIGH level MACHINE disturbance event	DMC1	Yes	NA
Distance to nearest MEDIUM level MACHINE disturbance event	DMC2	Yes	NA
Distance to nearest LOW level MACHINE disturbance event	DMC3	Yes	NA
Distance to nearest HIGH level PEOPLE disturbance event	DPC1	Yes	NA
Distance to nearest MEDIUM level PEOPLE disturbance event	DPC2	Yes	NA
Distance to nearest LOW level PEOPLE disturbance event	DPC3	Yes	NA

5.2.2.4 Statistical analysis – Hurdle model

Many of the count datasets contained a larger proportion of zero values than would be expected by a poisson or negative binomial distribution and are described as Zero-Inflated (Zuur et al., 2009).

Zero inflation is typically modelled in two ways with data being generated by two underlying, but

different processes (Lyashevskaya et al., 2016). The first method is referred to as a mixture model and the second, a Hurdle model (Cragg, 1971, Zuur et al., 2009). The Hurdle model is a two part model that specifies one process for the zero counts and another for the positive counts; a positive count occurs once a threshold is crossed i.e. a hurdle is cleared. In a Hurdle model, all zero observations are considered true zeros and were the method used in these analyses (see Chapter 3: Section 3.2.4 for further details on Hurdle model analysis).

In this aspect of the analysis and as a consequence of over-dispersion, a negative binomial distribution was employed for the count part and a binomial distribution for the zeros. Data exploration, model selection and model validation followed the process outlined in Chapter 3. A logical approach, based on ecological understanding and following good data exploration was taken for the inclusion of interactions. It should be noted that if interactions are included, then the corresponding main terms must also be included (Zuur et al., 2009).

The Hurdle model determines and reports on the significance of influential terms within each covariate i.e. 2008 within 'year'. However, the Chi square (χ^2) and significance (p -value) for each individual main term (e.g. year), as well as the χ^2 and p -value for each interaction term should be reported (Zuur et al., 2009). To obtain this, each term was dropped from the full model and compared with the MAM using the likelihood ratio testing (lrtest).

Part A

Pre-construction (years 2006 – 2009)

5.3 Results

5.3.1 Spatial autocorrelation (Moran's I Statistic) summary

Results from Ripley's K and Anselin Local Moran's I analysis (Chapter 4) showed that for combined months April – September and for months October – March, all nine SPA species displayed spatial clustering (autocorrelation) in their distribution across Abberton Reservoir. To further investigate the spatial pattern of each species, Moran's I statistic was calculated for each month (April – September) across the Main and Central Sections. These two sections were those subject to construction activity with analysis pre-construction providing a baseline (Chapter 5, Part A) upon which impacts of construction activity can be assessed (Chapter 5, Part B).

With the exception of September, the spatial pattern (using Moran's I statistic) for each species varied across the months and between the years (Table 5.2). During September, waterfowl counts for the majority of SPA species were highest (for the April – September period) with birds displaying spatial autocorrelation i.e. their distribution across the reservoir was not random. During months when waterfowl counts are typically low (May, June and July), the distribution pattern was random. The exception is Mute Swan for which counts were consistently high from June through to September, during which time they exhibit a clustered distribution. In addition to Mute Swan, Great Crested Grebe were the only other species present every month during the pre-construction years with other species, notably Wigeon and Teal absent for several months of the year.

Table 5.2: Results of spatial autocorrelation pattern (using Moran's I statistic) for nine Abberton Reservoir SPA species pre-construction. NA refers to where counts for that month/year were zero.

Year	Month	Spatial autocorrelation pattern (Moran's I statistic)								
		Gadwall	Shoveler	Teal	Wigeon	Coot	Tufted Duck	Pochard	Mute Swan	Great Crested Grebe
2006	April	Random	Clustered	Random	Random	Clustered	Clustered	Random	Clustered	Random
	May	Random	NA	Random	NA	Random	Random	Random	Random	Clustered
	June	Clustered	Random	NA	NA	Random	Clustered	NA	Clustered	Clustered
	July	Random	NA	NA	Random	Clustered	Random	NA	Clustered	Random
	August	Random	Clustered	Clustered	NA	Clustered	Clustered	Clustered	Clustered	Clustered
	September	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered
2007	April	Random	Random	Random	Clustered	Clustered	Clustered	Random	Random	Random
	May	Clustered	Random	NA	NA	Clustered	Clustered	Random	Random	Random
	June	Random	NA	NA	NA	Random	Clustered	Random	Clustered	Clustered
	July	NA	NA	NA	NA	NA	NA	NA	Clustered	Random
	August	Clustered	Random	Random	NA	Clustered	Clustered	Clustered	Clustered	Random
	September	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered
2008	April	Random	Clustered	Random	Random	Clustered	Clustered	Random	Random	Clustered
	May	Random	Random	NA	NA	Clustered	Random	NA	Clustered	Clustered
	June	Random	NA	Random	NA	Clustered	Clustered	NA	Clustered	Clustered
	July	NA	NA	NA	NA	Clustered	Random	Random	Clustered	Random
	August	Clustered	NA	NA	NA	Clustered	Clustered	Random	Clustered	Random
	September	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered
2009	April	Random	Random	Random	Random	Clustered	Clustered	Clustered	Clustered	Clustered
	May	Clustered	Random	NA	NA	Random	Random	NA	Clustered	Clustered
	June	Random	NA	NA	NA	Clustered	Clustered	NA	Clustered	Random
	July	NA	NA	NA	NA	Clustered	NA	NA	Clustered	Random
	August	Clustered	Clustered	Random	Random	Clustered	Clustered	Clustered	Clustered	Clustered
	September	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered

5.3.2 Species analysis pre-construction

5.3.2.1 Gadwall

Spatial distribution analysis from Chapter 4 showed that for combined months April – September 2006 - 2009, Gadwall were mostly aggregated into the Western Section except during 2009, when dense clusters were observed for the Central Section. During April – September, the Main Section was not identified as being especially important. Those present however, showed a preference for the edges of the reservoir and for Wigborough and Hide Bay.

Results from the Hurdle model for Gadwall pre-construction are presented in Table 5.3. For the count component, year ($X^2 = 30.272$, $df = 16$, $p < 0.001$); Section ($X^2 = 23.372$, $df = 18$, $p < 0.001$); % macrophyte ($X^2 = 6.778$, $df = 18$, $p < 0.01$); temperature ($X^2 = 11.955$, $df = 18$, $p < 0.001$) and total rainfall ($X^2 = 18.737$, $df = 18$, $p < 0.001$) were all identified as significant (main term) predictors for numbers of Gadwall. The effect of 2007, the Main Section, % macrophyte and total rainfall was negative while 2008 and temperature exerted a positive influence.

For the zero component, year ($X^2 = 68.691$, $df = 16$, $p < 0.001$); section ($X^2 = 64.143$, $df = 18$, $p < 0.001$); % macrophyte ($X^2 = 50.422$, $df = 18$, $p < 0.001$); water depth ($X^2 = 51.459$, $df = 18$, $p < 0.001$); temperature ($X^2 = 5.6086$, $df = 18$, $p < 0.05$) and total rainfall ($X^2 = 19.405$, $df = 18$, $p < 0.001$) were found to be significant predictors. Wind speed was also a significant predictor however a Chi-square (X^2) statistic could not be calculated due to differences in model comparison dataset size.

Of the significant predictors in the zero Hurdle model, 2008 and % macrophyte had a positive effect and 2009, the Main Section, water depth, temperature, wind speed and total rainfall all had a negative influence i.e. a count of zero Gadwall is predicted.

Table 5.3: Summary table of Hurdle model results for Gadwall in years pre-construction. Only variables with a confidence level of 95% (<0.05) are shown (see Appendix 5.2A for further details (applicable for all species)).

Variable	Z value	Significance (p-value)	Relationship
Count model (truncated negative binomial with log link)			
2007	-2.800	<0.01	-
2008	2.924	<0.01	+
Main section	-4.788	<0.001	-
% macrophyte	-2.633	<0.01	-
Temperature	3.556	<0.001	+
Total rainfall	-4.459	<0.001	-
Zero hurdle model (binomial with logit link)			
2008	3.384	<0.001	+
2009	-4.273	<0.001	-
Main Section	-8.377	<0.001	-
% macrophyte	7.189	<0.001	+
Water depth	-7.225	<0.001	-
Temperature	-2.393	<0.05	-
Wind speed	-7.538	<0.001	-
Total rainfall	-4.298	<0.001	-

Within the count component, water depth is not an important covariate however a significant negative relationship is observed for the zero hurdle. In the context of this model, it is interpreted that an increase in water depth causes an increase in the likelihood of a zero outcome (i.e. no Gadwall), and that, whilst water depth is not significant for numbers of Gadwall, they are associated with shallower water on a presence/absence basis.

Although excluded as a variable from model analysis due to collinearity issues, distance to shoreline is an important determinant of Gadwall with the majority of high counts occurring within 100m of the shoreline (Figure 5.1). At Abberton Reservoir, with the exception of the island, Hide and Wigborough Bay, Refgrid cells containing shallower water are, as expected, those closest to the shoreline.

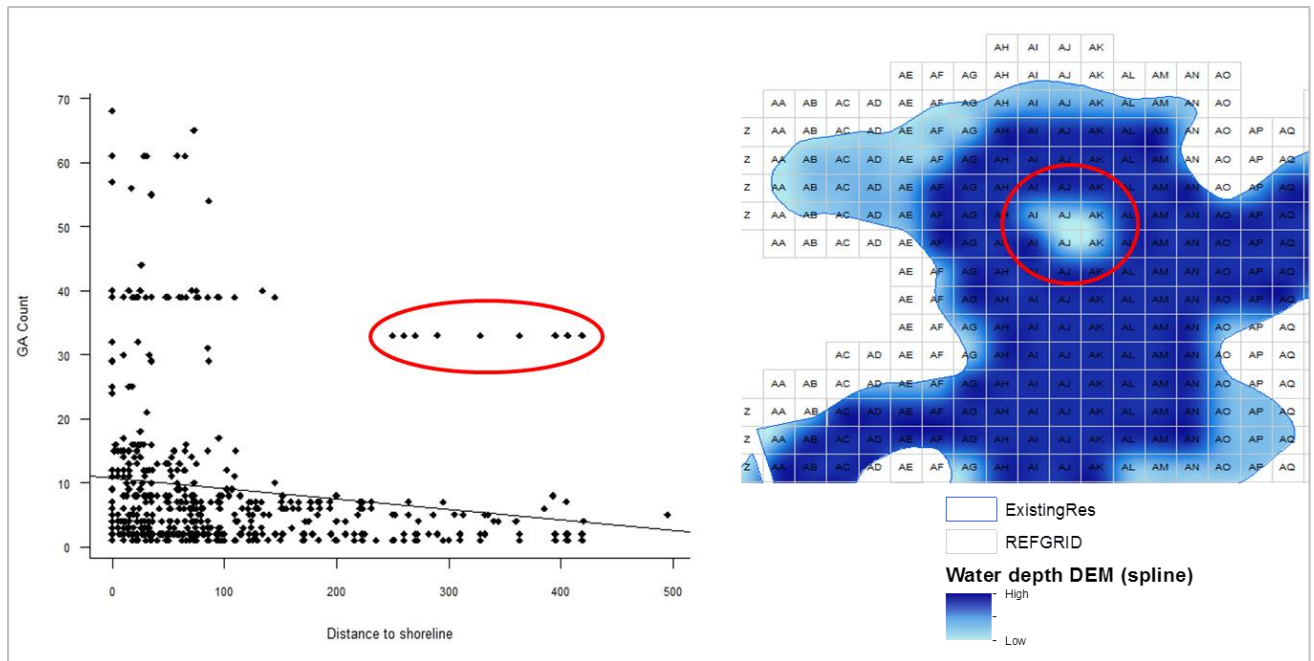


Figure 5.1: The relationship of Gadwall with distance to shoreline (m) at Abberton Reservoir (shown with a regression line (standard linear model $R^2 = 0.2387$, $p < 0.001$)). The nine counts highlighted on the left plot are associated with the Refgrid cells on or around the island (circled on the map), which becomes exposed at lower water levels.

Results from the Hurdle model (count component) show a negative association with increasing % cover of macrophyte and with the Main Section. This is due to Gadwall displaying a spatial preference for the Central Section and the edges of the reservoir. For the pre-construction years, the edges of the Main Section contained a concrete apron and in the Central Section, exposed shoreline; neither of these habitats are associated with dense macrophyte beds. Figure 5.2 shows that, although accounting for only 35% of available Refgrid cells in the Main and Central Section, Gadwall prefer those containing an edge habitat. The island, Hide Bay and Wigborough Bay also provide a form of edge habitat (and therefore roosting habitat) when they become exposed as the water levels draw down. However, because these features are completely submerged at higher water levels, they do not represent permanent habitats and are therefore excluded from the y category (Figure 5.2). This further highlights the importance of the reservoir edge to this species.

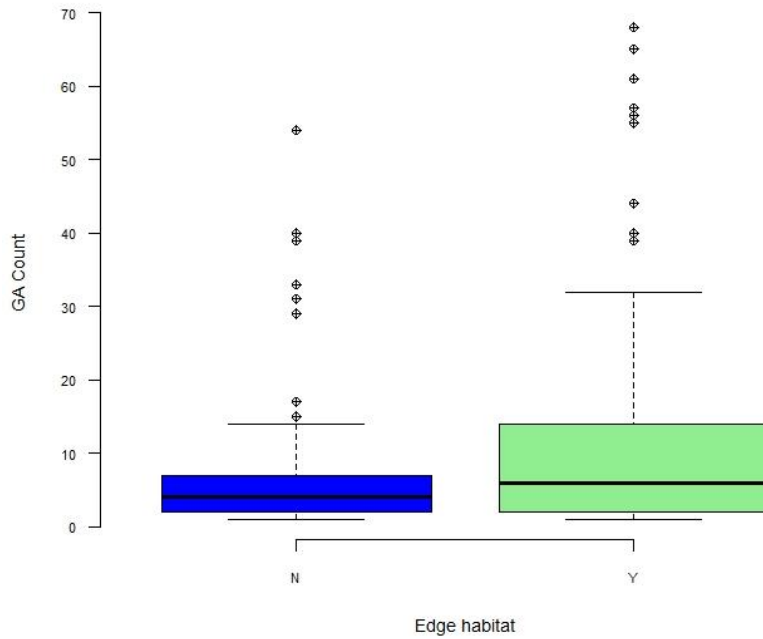


Figure 5.2: Location of Gadwall pre-construction in Refgrid cells containing edge habitat (197 cells (35%)) and those not containing edge habitat (363 cells (65%)). Y = Yes, Refgrid contains edge habitat, N = no edge habitat.

5.3.2.2 Shoveler

Analysis from Chapter 4 showed that for combined months April – September, Shoveler favoured the Western Section, the northern shoreline of the Central Section and within the Main Section, Hide and Wigborough Bay.

Results from the Shoveler Hurdle model pre-construction are presented in Table 5.4. For the count component, year was found to be the only significant covariate with 2007 and 2008 both having a negative effect. For the zero component, year ($X^2 = 78.477$, $df = 12$, $p < 0.001$); section ($X^2 = 18.425$, $df = 14$, $p < 0.001$); % macrophyte ($X^2 = 21$, $df = 14$, $p < 0.001$); water depth ($X^2 = 40.192$, $df = 14$, $p < 0.001$); temperature ($X^2 = 17.686$, $df = 14$, $p < 0.001$) and total rainfall ($X^2 = 35.013$, $df = 14$, $p < 0.001$) were all significant predictors. Wind speed was also a significant predictor however as in the Gadwall model, a Chi-square statistic could not be calculated.

Of the significant predictors in the zero Hurdle model, only the relationship with % macrophyte was positive and associated with the prediction of a count (the presence of Shoveler) outcome. Years

2007 and 2009, the Main Section, increasing water depth, temperature, wind speed and total rainfall were all found to be negative predictors with increases in these variables associated with the absence of Shoveler.

Table 5.4: Summary table of Hurdle model results for Shoveler in years pre-construction. Only variables with a confidence level of 95% (<0.05) are shown.

Variable	Z value	Significance (p-value)	Relationship
Count model (truncated negative binomial with log link)			
2007	-4.768	<0.001	-
2008	-2.006	<0.05	-
Zero hurdle model (binomial with logit link)			
2007	-3.999	<0.001	-
2009	-6.393	<0.001	-
Main Section	-4.472	<0.001	-
% macrophyte	4.647	<0.001	+
Water depth	-6.393	<0.001	-
Temperature	-4.232	<0.001	-
Wind speed	-7.005	<0.001	-
Total rainfall	-5.563	<0.001	-

Shoveler are classified within the dabbling duck guild and largely feed from the surface of the water. Similar to Gadwall, analysis found water depth to be a significant predictor for the presence (versus absence) of Shoveler, but not for numbers counted. This species also displays a preference for edge habitat, the island and for Refgrid cells within 200m of the shoreline (Figure 5.3) although the relationship and distances observed suggests Shoveler are less restricted to the shoreline than Gadwall. That said, the high counts recorded on and around the island (September 2009) could be particularly influential and removing these may alter the relationship.

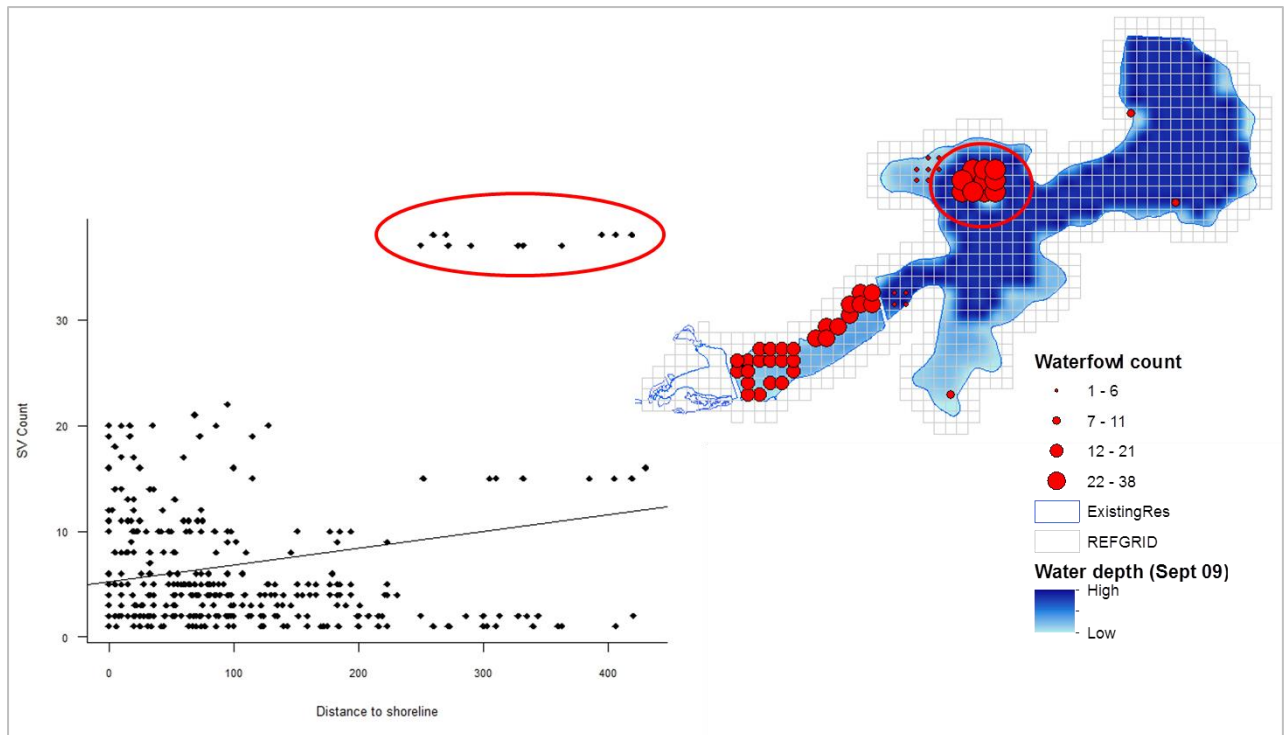


Figure 5.3: The relationship between Shoveler and distance to the shoreline (m) at Abberton Reservoir pre construction (shown with a regression line (standard linear model $R^2 = 0.04269$, $p < 0.001$)). The high counts highlighted on the left plot are associated with the Refgrid cells on or around the island (highlighted on the map).

5.3.2.3 Teal

Spatial distribution analysis in Chapter 4 for years pre-construction found no particular clustering pattern for Teal during combined months April – September however higher counts were observed for the Central and Western Sections. Clusters of Teal that were present within the Main Section were most pronounced within Wigborough Bay and on the island during 2009.

Results from further statistical analysis using a Hurdle model are presented in Table 5.5. Year was found to be a significant covariate ($X^2 = 31.23$, $df = 18$, $p < 0.001$) with fewer Teal present within the Main and Central Sections during 2007 and 2009 compared with 2006 and 2008. Section ($X^2 = 10.187$, $df = 20$, $p < 0.01$), water depth ($X^2 = 5.8537$, $df = 20$, $p < 0.05$), temperature ($X^2 = 9.4032$, $df = 20$, $p < 0.01$), and total rainfall ($X^2 = 10.027$, $df = 20$, $p < 0.01$) were also found to be important covariates in the count component for Teal. The negative effect of the Main Section was particularly pronounced with Teal demonstrating a firm preference for the Central Section (Figure 5.4). Numbers

of Teal were found to decrease with increasing total rainfall and water depth but to increase with higher temperatures; a likely result of increased waterfowl numbers in August and September.

Results from the zero component show that year ($\chi^2 = 68.412$, $df = 18$, $p < 0.001$); % macrophyte ($\chi^2 = 18.282$, $df = 19$, $p < 0.001$); water depth ($\chi^2 = 73.431$, $df = 19$, $p < 0.001$); temperature ($\chi^2 = 17.709$, $df = 20$, $p < 0.001$); wind speed ($\chi^2 = 22.627$, $df = 20$, $p < 0.001$); total rainfall ($\chi^2 = 14.548$, $df = 20$, $p < 0.001$) and the interaction between % macrophyte and water depth ($\chi^2 = 12.562$, $df = 20$, $p < 0.001$) were all important for the prediction of a zero or positive count of Teal. Excluding the interaction, the effect of these variables was negative with increasing values of each associated with a zero outcome i.e. no Teal. The positive effect of the interaction between % macrophyte and water depth may be interpreted as when % macrophyte increases, the effect of water depth on a positive or zero outcome of Teal increases.

Table 5.5: Summary table of Hurdle model results for Teal in years pre-construction. Only variables with a confidence level of 95% (<0.05) are shown.

Variable	Z value	Significance (p-value)	Relationship
Count model (truncated negative binomial with log link)			
2007	-2.028	<0.05	-
2009	-2.784	<0.01	-
Main Section	-3.208	<0.001	-
Water depth	-2.481	<0.01	-
Temperature	3.133	<0.001	+
Total rainfall	-3.348	<0.001	-
Zero hurdle model (binomial with logit link)			
2007	-4.463	<0.001	-
2009	-5.074	<0.001	-
% macrophyte	-1.975	<0.05	-
Water depth	-7.596	<0.001	-
Temperature	-4.148	<0.001	-
Wind speed	-4.277	<0.001	-
Total rainfall	-3.598	<0.001	-
% macrophyte* water depth	3.647	<0.001	+

N.B. Where * indicates an interaction

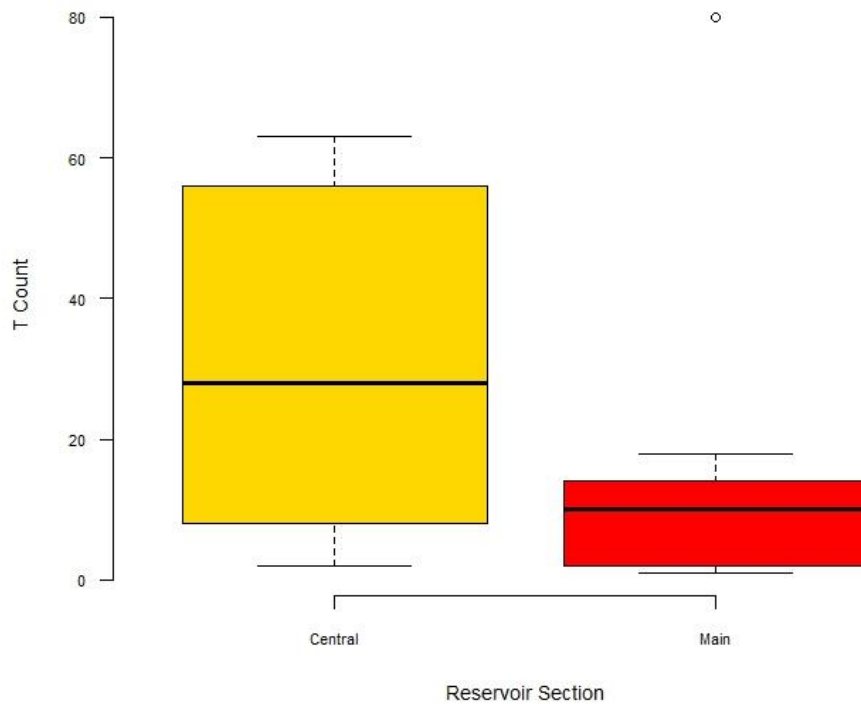


Figure 5.4: Boxplot of numbers of Teal present in years pre-construction within the Main and Central Sections.

Findings indicate that Teal, a dabbling duck do not show any spatial preference for areas of Abberton Reservoir containing dense macrophyte beds. Given the preference for shallower water and the Central Section, it is likely that this is due to Teal roosting or feeding close to the edge of the reservoir. This is supported by Figure 5.5 which shows that higher counts of Teal are associated with distances close to the shoreline of the reservoir and at lower water levels, the island and Wigborough bay. At Abberton Reservoir, these areas contain a proportion of dry land or in the case of the Main Section shorelines, concrete, and as such do not contain high macrophyte cover compared with Refgrid cells containing 100% water.

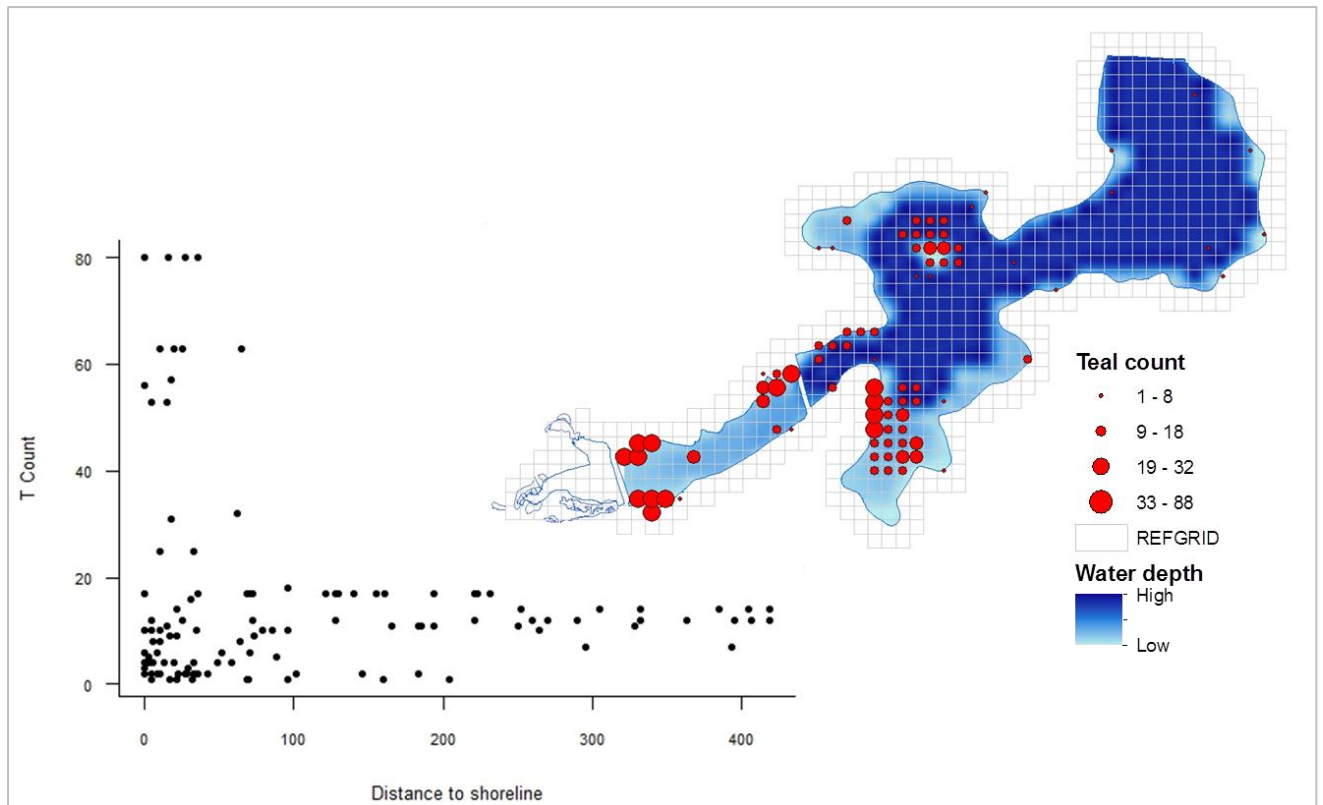


Figure 5.5: The relationship between Teal and distance to shoreline (m) at Abberton Reservoir pre construction. The counts associated with distances further from the shoreline are associated with Refgrid cells on or around the island and in Wigborough Bay and explain the non-significant regression result.

5.3.2.4 Wigeon

Spatial distribution analysis in Chapter 4 reported that for combined months of April – September 2006 and 2009, significant clusters of Wigeon were only observed for the Central and Western Sections. During 2007 and 2008, aggregations were concentrated within Wigborough and Hide Bay; also found to be favoured by other dabbling duck species using this section.

Hurdle model analysis (Table 5.6) found year ($\chi^2 = 227.01$, $df = 12$, $p < 0.001$), water depth ($\chi^2 = 282.37$, $df = 18$, $p < 0.01$), wind speed ($\chi^2 = 38.454$, $df = 18$, $p < 0.001$) and the interaction between water depth and wind speed ($\chi^2 = 20.453$, $df = 19$, $p < 0.001$) to be important predictor variables for numbers of Wigeon at Abberton Reservoir. From the year variable, 2007 was found to be a negative predictor as was the interaction and both other significant covariates within the final model.

The zero component of the Hurdle model was found to contain more significant covariates than the count component and includes year ($\chi^2 = 196.88$, $df = 17$, $p < 0.001$); Section ($\chi^2 = 7.7468$, $df = 19$, $p < 0.01$); % macrophyte ($\chi^2 = 66.634$, $df = 18$, $p < 0.001$); temperature ($\chi^2 = 18.63$, $df = 19$, $p < 0.001$); wind speed ($\chi^2 = 193.77$, $df = 19$, $p < 0.001$); total rainfall ($\chi^2 = 101.25$, $df = 19$, $p < 0.001$) and the interaction between water depth and % macrophyte ($\chi^2 = 12.207$, $df = 19$, $p < 0.001$). For the binomial component, 2008, increasing % macrophyte and temperature were found to have a positive influence and are associated with the prediction of a count outcome. The other significant covariates in the zero model were found to exert a negative influence and are therefore linked to a predicted Wigeon count outcome of zero. For wind speed, it is suggested that Wigeon at Abberton Reservoir prefer calmer conditions as increasing wind speeds are associated with both the prediction of fewer Wigeon (count component) and the prediction of encountering no Wigeon (zero component).

Table 5.6: Summary table of Hurdle model results for Wigeon in years pre-construction. Only variables with a confidence level of 95% (<0.05) are shown.

Variable	Z value	Significance (p-value)	Relationship
Count model (truncated negative binomial with log link)			
2007	-4.333	<0.001	-
Water depth	-3.452	<0.001	-
Wind speed	-2.224	<0.05	-
Water depth*wind speed	-4.621	<0.001	-
Zero hurdle model (binomial with logit link)			
2007	-2.706	<0.01	-
2008	3.980	<0.001	+
2009	-4.745	<0.001	-
Main Section	-2.866	<0.001	-
% macrophyte	6.113	<0.001	+
Temperature	4.139	<0.001	+
Wind speed	-11.340	<0.001	-
Total rainfall	-8.344	<0.001	-
Water depth*% macrophyte	-3.455	<0.001	-

N.B. Where * indicates an interaction

Wigeon belong to the dabbling duck guild and almost entirely feed by grazing on individual leaves of plants (Guillemain et al., 2002b). Results here suggest that at Abberton Reservoir, they are associated with areas containing dense vegetation, shallower water, with further analysis demonstrating that flocking is more apparent in Refgrid cells located within 200m of the shoreline (Figure 5.6). The 10 counts of 250 Wigeon highlighted below were recorded in September 2008 and reflect the importance of Hide Bay at this time to this species. This is likely due to low water levels exposing areas of Hide, and indeed Wigborough Bay which then become attractive to dabbling ducks. The effect of lower water levels explains the spatial distribution and relationship of Wigeon with increased distances from the shoreline.

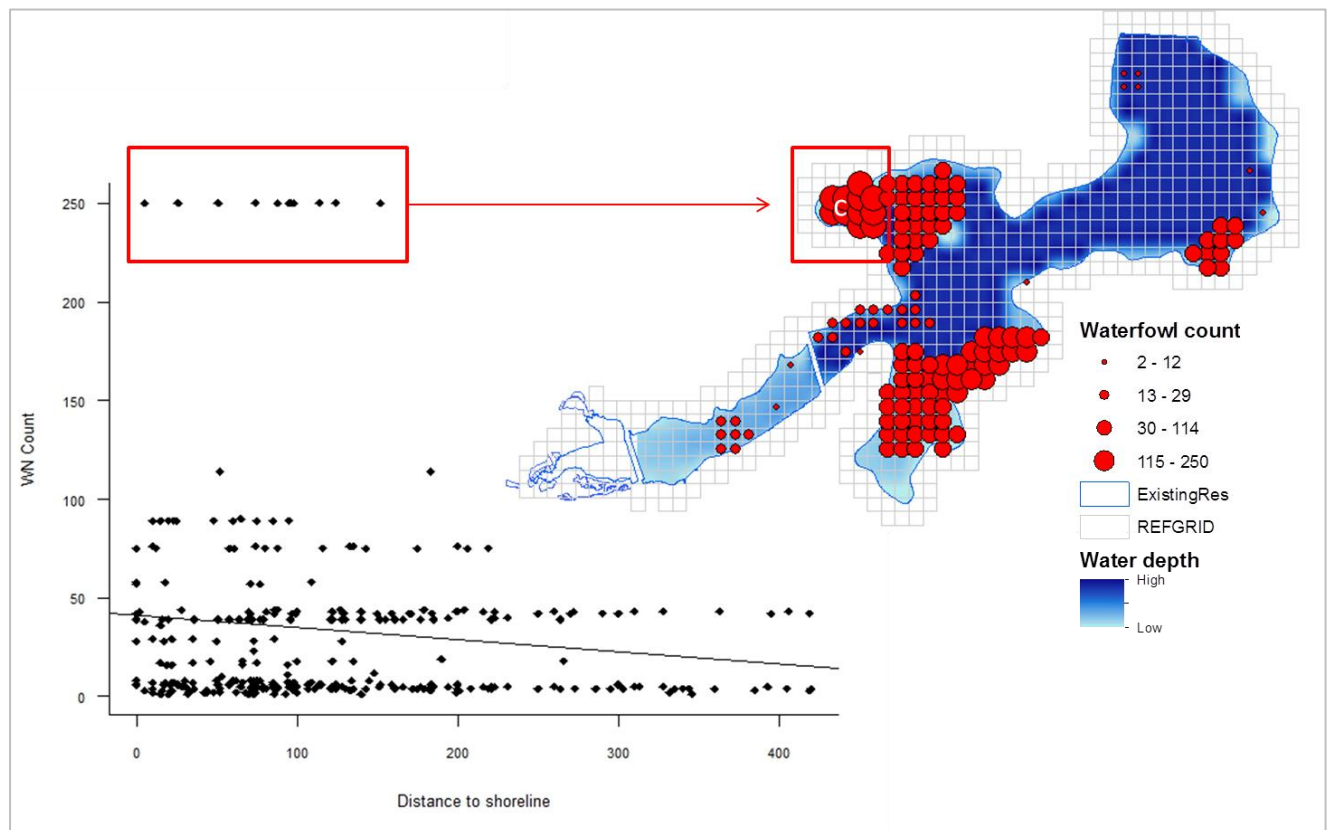


Figure 5.6: The relationship between Wigeon and distance to the shoreline (m) at Abberton Reservoir pre construction (shown with a regression line (standard linear model $R^2 = 0.01106$, $p < 0.05$)). The high counts highlighted on the left plot are associated with the Refgrid cells in Hide Bay during September 2008 (highlighted on the map). The presence of Wigeon in Hide and Wigborough bay when water levels are drawn down explains the occurrence and relationship of this species with increased distances from the shoreline.

5.3.2.5 Coot

Previous analysis has shown that in years pre-construction, Coot displayed a high degree of clustering which, across all three sections, was most pronounced in the Western Section and around Hide Bay; particularly in 2009.

Hurdle model analysis found that year ($X^2 = 90.048$, $df = 19$, $p < 0.001$); % macrophyte ($X^2 = 7.6675$, $df = 21$, $p < 0.01$); temperature ($X^2 = 215.56$, $df = 20$, $p < 0.001$); wind speed ($X^2 = 124.42$, $df = 20$, $p < 0.001$); total rainfall ($X^2 = 348.9$, $df = 21$, $p < 0.001$) and the interaction between wind speed and rain ($X^2 = 76.749$, $df = 21$, $p < 0.001$) were all influential on numbers of Coot. 2008, % macrophyte, increasing temperature and wind speed were found to be positive predictors and the influence of 2007, total rainfall and the interaction of temperature and wind speed negative.

The zero binomial component, predicting a zero or count outcome showed that year ($X^2 = 178.11$, $df = 19$, $p < 0.001$); Section ($X^2 = 446.44$, $df = 21$, $p < 0.001$); % macrophyte ($X^2 = 70.073$, $df = 20$, $p < 0.001$); temperature ($X^2 = 6.7227$, $df = 18$, $p < 0.01$); wind speed ($X^2 = 97.155$, $df = 21$, $p < 0.001$); total rainfall ($X^2 = 17.123$, $df = 21$, $p < 0.001$) and the interaction between % macrophyte and water depth ($X^2 = 12.626$, $df = 21$, $p < 0.001$) were all significant predictor variables. Only the increase in % macrophyte is associated with the prediction of a count outcome further supporting findings from the count component that numbers of Coot are associated with areas of Abberton Reservoir containing dense aquatic vegetation. All other variables in the zero model are shown to exhibit a negative relationship and are associated with an increased chance of a zero outcome (Table 5.7). For temperature and total wind speed, results initially appear conflicting however it is a likely product of spatial autocorrelation.

Table 5.7: Summary table of Hurdle model results for Coot in years pre-construction. Only variables with a confidence level of 95% (<0.05) are shown.

Variable	Z value	Significance (p-value)	Relationship
Count model (truncated negative binomial with log link)			
2007	-2.702	<0.01	-
2008	7.799	<0.001	+
% macrophyte	2.766	<0.01	+
Temperature	12.990	<0.001	+
Wind speed	6.930	<0.001	+
Total rainfall	-6.247	<0.001	-
Temperature*wind speed	-8.786	<0.001	-
Zero hurdle model (binomial with logit link)			
2007	-9.673	<0.001	-
2008	-2.325	<0.05	-
2009	-10.079	<0.001	-
Main Section	-21.458	<0.001	-
% macrophyte	6.396	<0.001	+
Temperature	-2.614	<0.01	-
Wind speed	-9.243	<0.001	-
Total rainfall	-4.099	<0.001	-
% macrophyte*water depth	-3.541	<0.001	-

Aggregations of Coot were particularly high each September with dense clusters located within the Central Section during 2007 and within the vicinity of Hide Bay during 2009. Figure 5.7 highlights these high counts which also show the relationship of Coot with distance to shoreline and with water depth. A weak negative relationship was observed for water depth with numbers shown to decline with increasing depth (Table 5.7 above and Figure 5.7 below).

Similar to other species analysed, Coot are associated with distance to shoreline however unlike Gadwall and Wigeon, higher numbers are associated with increased distances with counts of up to 150 birds located within 400m of the shoreline. This species shows a high degree of spatial autocorrelation at higher densities, illustrated by the same number of birds recorded at increasing distances from the shoreline i.e. a straight line could be drawn through the data points in Figure 5.7. This is due to the PDA and associated software (see Chapter 3: Section 3.1.2) automatically splitting

the total Coot count equally between the areas of reservoir they cover. For example, a raft of 3,450 birds was recorded across 25 close proximity Refgrid cells in September 2009. This is also the likely reason for the relatively weak relationship observed for Coot and distance to shoreline; indicated by results of regression analysis (Figure 5.7).

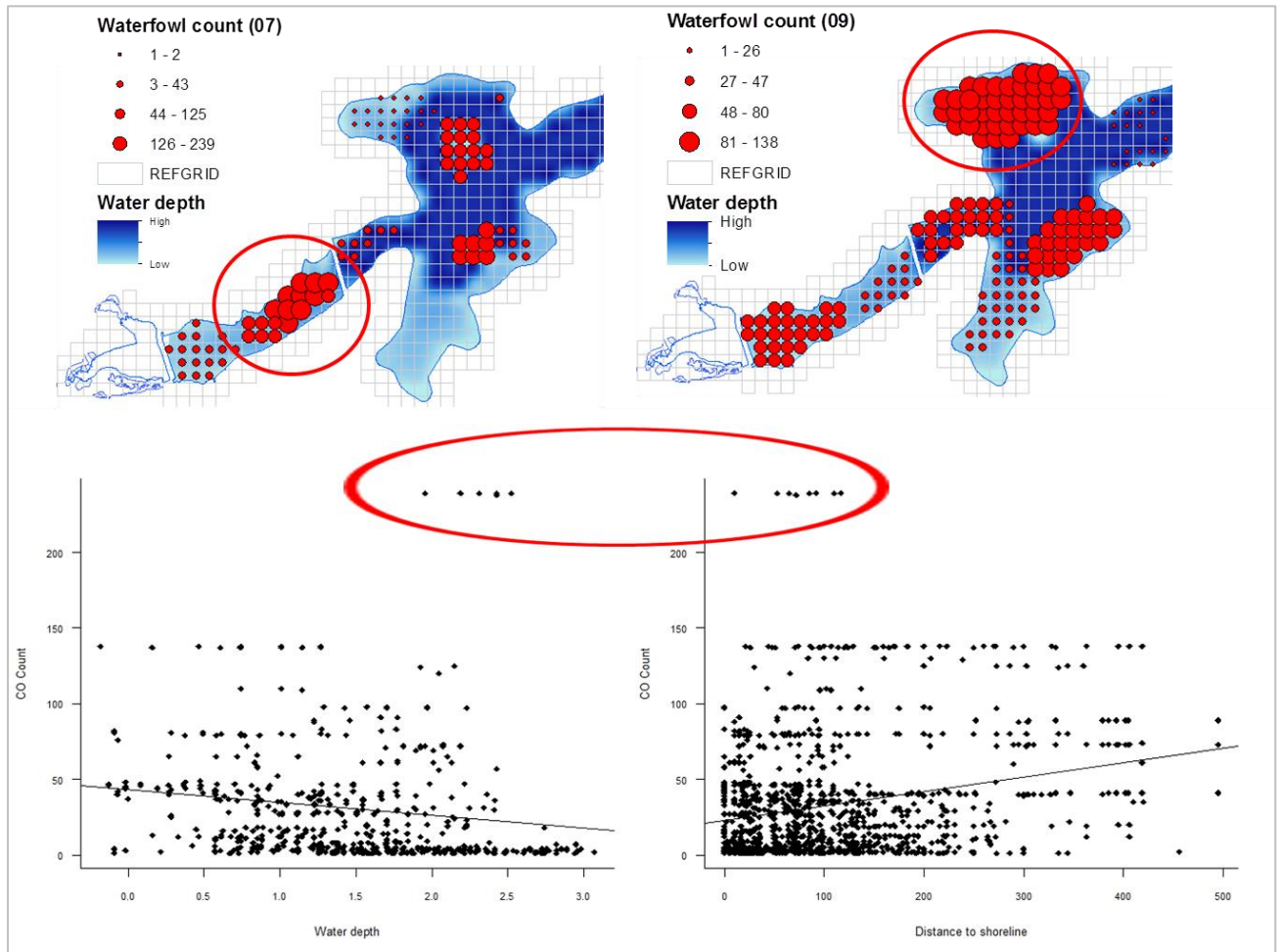


Figure 5.7: The relationship between Coot and water depth at Abberton Reservoir (left scatterplot) pre-construction (shown with a regression line (standard linear model $R^2 = 0.01947$, $p < 0.001$)) and with distance to shoreline (right scatterplot standard linear model $R^2 = 0.05219$, $p < 0.001$). The high counts highlighted are associated with the Refgrid cells within the Central Section during September 2007 and Hide Bay during September 2009 (both highlighted on the map). Units for both plots are in metres (m).

5.3.2.6 Tufted Duck

Preliminary analysis found this species to have a clustered yet variable distribution pattern; results presented here determine the environmental conditions driving Tufted Duck spatial distribution in years pre-construction which can be used as a baseline against disturbance assessment (Part B).

Results of Hurdle model analysis are summarised in Table 5.8 and show that for year ($\chi^2 = 24.929$, $df = 17$, $p < 0.001$); % macrophyte ($\chi^2 = 9.4279$, $df = 19$, $p < 0.01$); water depth ($\chi^2 = 70.526$, $df = 18$, $p < 0.001$); temperature ($\chi^2 = 7.8957$, $df = 19$, $p < 0.01$); wind speed ($\chi^2 = 70.221$, $df = 18$, $p < 0.001$) and the interaction between water depth and wind speed ($\chi^2 = 50.66$, $df = 19$, $p < 0.001$) were all important for this species. The positive effect of increasing water depth and wind speed was particularly strong which is supported by the significance of the interaction between the two. Within this study, Tufted Duck is the only species shown to be associated with parts of Abberton Reservoir containing deeper water (Figure 5.8) with clustering and high Refgrid counts located at depths exceeding 1m. Further to this, 20 counts of 138 birds recorded in September 2008 were removed from the Hurdle model as they were regarded as outliers; potentially explaining results, or lack thereof, from regression analysis. These removed counts were part of a large raft of birds highlighted on the map in Figure 5.8 and all occurred in deeper water during September 2008. This, together with the Hurdle model results shows that 2008 was a particularly good year for Tufted Duck and that water depth is a key predictor.

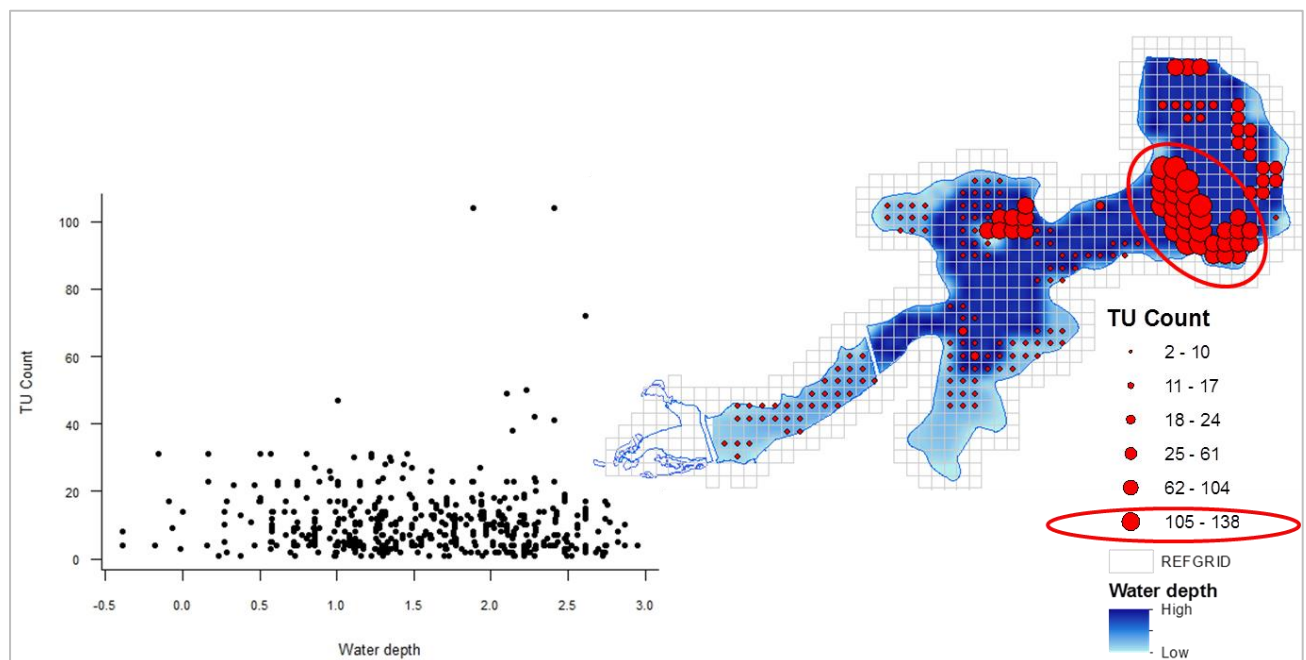


Figure 5.8: The relationship between counts of Tufted Duck and water depth (m) at Abberton Reservoir pre-construction. The high counts shown on the left plot are associated with deeper water depths. The right plot shows a map of Abberton Reservoir and highlights the 20 higher counts that were removed for hurdle analysis.

Other notable findings include the association of this species with aquatic vegetation and wind speed. The Hurdle model predicts increased numbers and a count outcome for the higher percentages of macrophyte ($\chi^2 = 75.063$, $df = 19$, $p < 0.001$) and higher numbers yet a greater chance of a zero count for increasing wind speed ($\chi^2 = 89.86$, $df = 18$, $p < 0.001$). This suggests that during high winds, Tufted Duck form large aggregations which increases the count for those Refgrid cells, but reduces the overall number occupied.

Other covariates significant in predicting a count or zero outcome are section ($\chi^2 = 12.855$, $df = 19$, $p < 0.001$), temperature ($\chi^2 = 306.38$, $df = 19$, $p < 0.01$), total rainfall ($\chi^2 = 68.762$, $df = 19$, $p < 0.001$) and the interaction between wind speed and temperature ($\chi^2 = 59.196$, $df = 19$, $p < 0.001$). Those associated with an increased chance of a zero count outcome are the Main Section and increased rainfall and temperature. Similar to wind speed, results for temperature suggest pronounced clustering for this species occurs at higher temperatures e.g. during August and September. The interaction between temperature and wind speed means that when temperature increases so does the effect of wind speed on counts of Tufted Duck.

Table 5.8: Summary table of Hurdle model results for Tufted Duck in years pre-construction. Only variables with a confidence level of 95% (<0.05) are shown.

Variable	Z value	Significance (p-value)	Relationship
Count model (truncated negative binomial with log link)			
2009	3.857	<0.001	+
% macrophyte	3.058	<0.001	+
Water depth	8.715	<0.001	+
Temperature	2.817	<0.001	+
Wind speed	3.007	<0.001	+
Water depth*wind speed	-7.156	<0.001	-
Zero hurdle model (binomial with logit link)			
2007	-6.593	<0.001	-
2008	-3.023	<0.001	-
2009	-8.668	<0.001	-
Main Section	-3.685	<0.001	-
% macrophyte	8.768	<0.001	+

Temperature	-12.923	<0.001	-
Wind speed	-8.662	<0.001	-
Total rainfall	-7.937	<0.001	-
Temperature*wind speed	7.564	<0.001	+

5.3.2.7 Pochard

Distribution analysis of combined months April – September showed Pochard to favour the Western and Main Section. No obvious spatial patterns were observed between years however similarities with Tufted Duck, particularly during 2008 were noted. Upon further investigation, this was mainly due to aggregations of both species within the northern half of the reservoir during September 2008 (Figure 5.9).

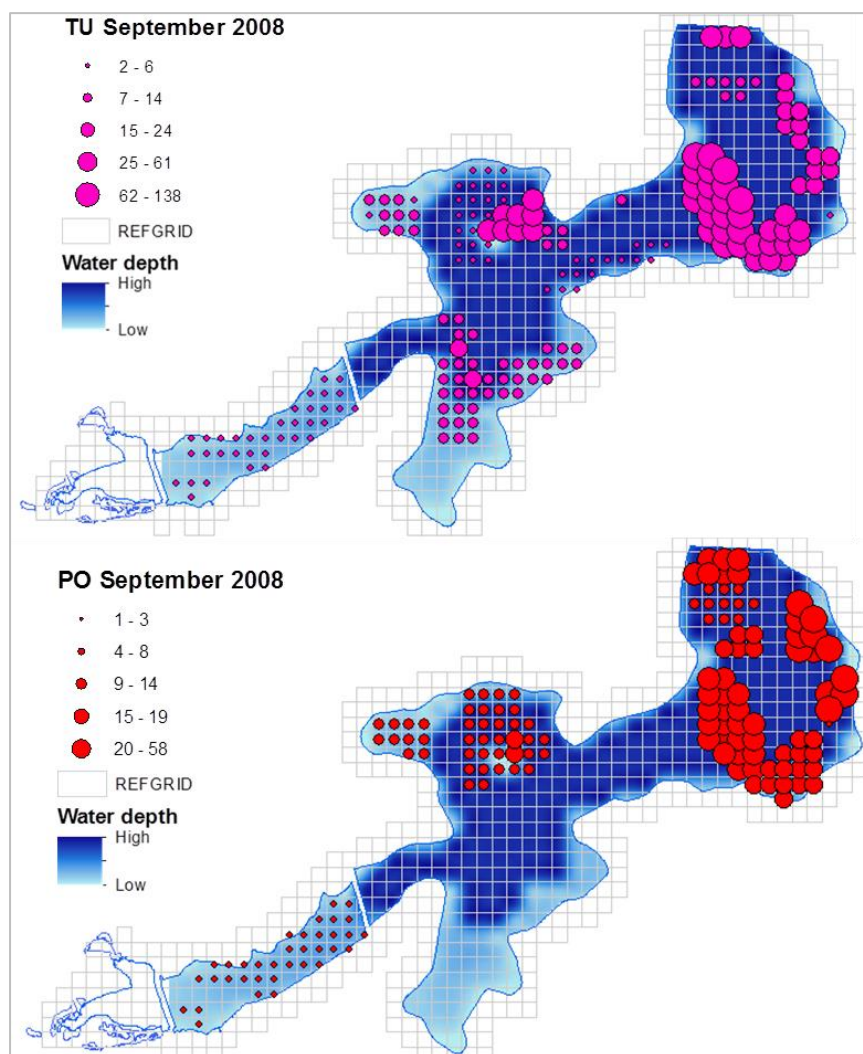


Figure 5.9: Spatial distribution plot of Tufted Duck (top map) and Pochard (bottom map) during September 2008.

Statistical analysis to determine if any particular environmental variables were driving this pattern did not produce similar results although wind speed and % macrophyte were found to be important for both species. It should be emphasised however that the significance level for % macrophyte within the Pochard count model was fairly low and consequently should be interpreted with caution. Considering this, results are likely to be the product of spatial autocorrelation with birds of a similar ecological niche gathering in large flocks, presumably for increased safety and shelter. Furthermore, the zero Hurdle model (summary in Table 5.9) found wind speed ($\chi^2 = 188.76$, $df = 17$, $p < 0.001$), to be significant and increased rainfall influenced both numbers ($\chi^2 = 32.308$, $df = 18$, $p < 0.001$), and occurrence ($\chi^2 = 22.99$, $df = 18$, $p < 0.001$) of Pochard, providing evidence that this species aggregates for shelter. Clustering was also most pronounced at increased distances from the shoreline (Figure 5.10), although aggregations were also found close to the reservoir edge, explaining the low observed R^2 value and why water depth was not influential for Pochard but was for Tufted Duck.

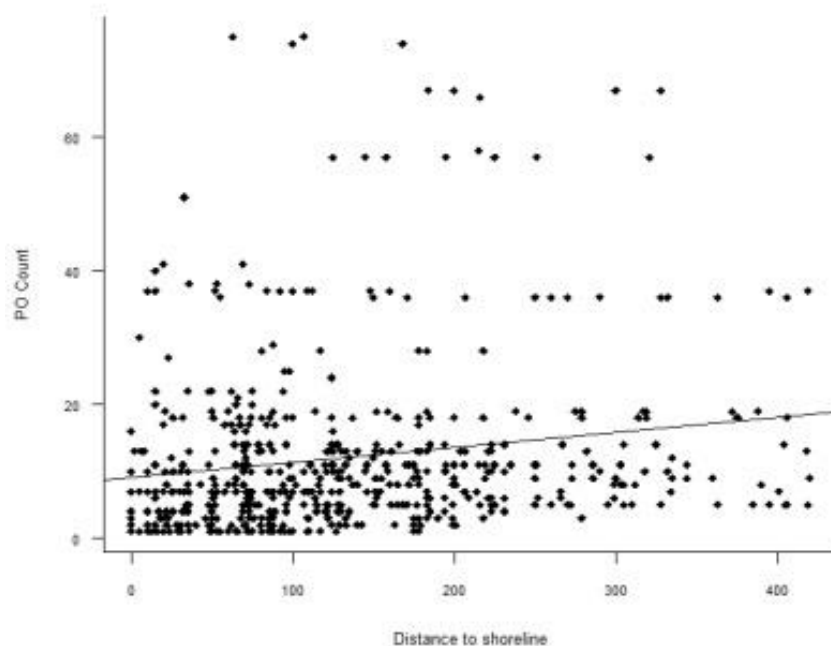


Figure 5.10: The relationship between Pochard and distance to shoreline (m) showing counts increasing with distances further from the shoreline (shown with a regression line (standard linear model $R^2 = 0.02798$, $p < 0.001$)).

Except for consistent presence within the Western Section, no obvious differences were observed between sections when data for April – September were combined (Chapter 4). The Hurdle model however found Section to be significant for both count ($X^2 = 26.109$, $df = 18$, $p < 0.001$) and zero components ($X^2 = 78.777$, $df = 18$, $p < 0.001$) with this species pre-construction preferring the Main Section compared with the Central Section.

Table 5.9: Summary table of Hurdle model results for Pochard in years pre-construction. Only variables with a confidence level of 95% (<0.05) are shown.

Variable	Z value	Significance (p-value)	Relationship
Count model (truncated negative binomial with log link)			
Main Section	5.230	<0.001	+
% macrophyte	-1.909	<0.05	-
Wind speed	-4.602	<0.001	-
Total rainfall	5.127	<0.001	+
Zero hurdle model (binomial with logit link)			
2007	-5.567	<0.001	-
2009	-6.978	<0.001	-
Main Section	-9.616	<0.001	-
% macrophyte	4.981	<0.001	+
Wind speed	-4.981	<0.001	-
Total rainfall	-4.677	<0.001	-

5.3.2.8 Mute Swan

Unlike migratory species, Mute Swan is present throughout the spring/summer period with counts at Abberton Reservoir typically peaking in July and August (Figure 5.11). In years pre-construction, this species were well distributed in good numbers throughout the reservoir with the Western and Central Sections along with areas near Wigborough and Hide Bay consistently containing aggregations.

Results of statistical analysis for the spring and summer months are shown in Table 5.10 and support previous spatial analysis that within Abberton Reservoir, this is a highly mobile and dispersed

species. With the exception of year ($\chi^2 = 53.652$, $df = 17$, $p < 0.001$) and section ($\chi^2 = 11.13$, $df = 19$, $p < 0.001$), only atmospheric environmental conditions were shown to be influential in the prediction of Mute Swan aggregations.

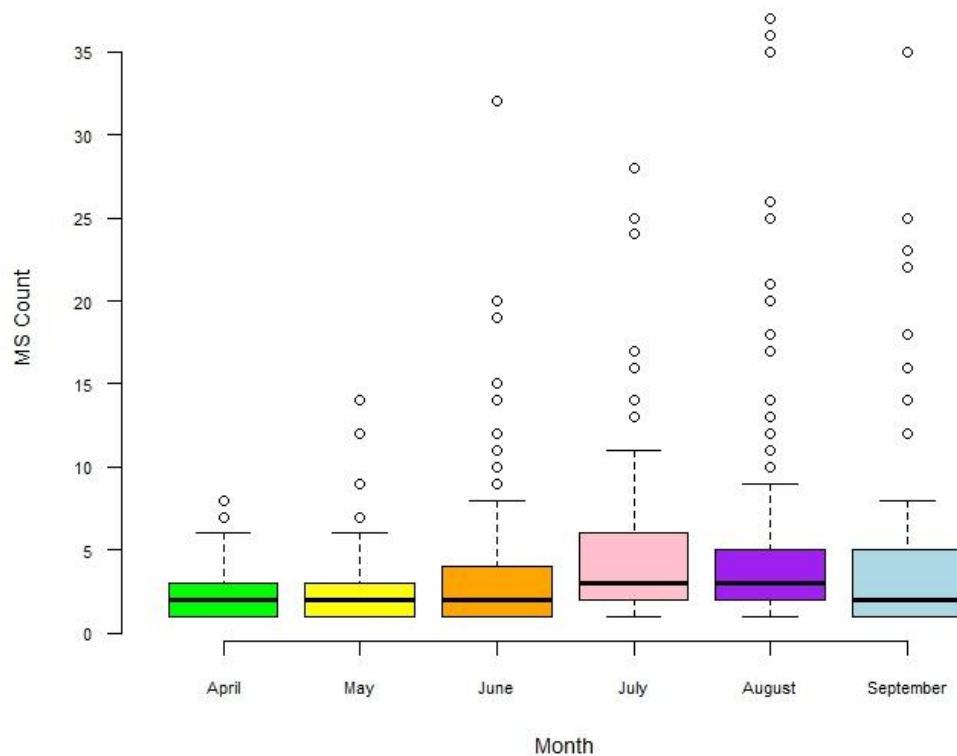


Figure 5.11: Numbers of Mute Swan at Abberton Reservoir (Main and Central Sections) during the spring and summer months.

Predictor variables accounting for higher numbers of Mute Swan were increased wind speed ($\chi^2 = 24.891$, $df = 18$, $p < 0.001$), temperature ($\chi^2 = 48.844$, $df = 19$, $p < 0.001$) and rainfall ($\chi^2 = 38.248$, $df = 18$, $p < 0.001$) with the effect of rainfall decreasing with increasing wind speeds ($\chi^2 = 18.805$, $df = 19$, $p < 0.001$). All of the variables found within the count component were also significant in accounting for the presence/absence of Mute Swan along with the interaction of temperature and rainfall ($\chi^2 = 35.404$, $df = 19$, $p < 0.001$). Variables associated with a species count (opposed to a zero) were increasing % macrophyte ($\chi^2 = 296.72$, $df = 19$, $p < 0.001$); temperature ($\chi^2 = 153.28$, $df =$

18, $p < 0.001$) and rainfall ($X^2 = 75.576$, $df = 18$, $p < 0.001$) while increasing wind speed resulted in the prediction of a zero count outcome ($X^2 = 70.681$, $df = 19$, $p < 0.001$).

The association with macrophyte cover is particularly noteworthy since it was the strongest relationship observed and suggests that Mute Swan occurrence is, to a certain extent dependent on aquatic vegetation.

Table 5.10: Summary table of Hurdle model results for Mute Swan in years pre-construction. Only variables with a confidence level of 95% (<0.05) are shown.

Variable	Z value	Significance (p-value)	Relationship
Count model (truncated negative binomial with log link)			
2007	-1.973	<0.05	-
2008	3.492	<0.001	+
Main Section	-3.289	<0.001	-
Temperature	7.244	<0.001	+
Wind speed	4.821	<0.001	+
Total rainfall	5.918	<0.001	+
Wind speed*total rainfall	-4.198	<0.001	-
Zero hurdle model (binomial with logit link)			
2007	5.594	<0.001	+
2008	5.164	<0.001	+
2009	6.025	<0.001	+
Main Section	-3.754	<0.001	-
% macrophyte	15.116	<0.001	+
Temperature	7.278	<0.001	+
Wind speed	-8.085	<0.001	-
Total rainfall	2.655	<0.01	+
Temperature*total rainfall	-3.501	<0.001	-

Despite its size and containing significant clusters of Mute Swan, the Main Section was found to be a predictor of a zero count and was also associated with lower count values. The preference for the Central Section may also explain the association of Mute Swan with areas located closer to the shoreline (Figure 5.12) as distances in this section are small in comparison.

Plotting the distance of Mute Swan to the shoreline also reveals a number of high counts directly on the shoreline. Since the edges of the reservoir in years pre-construction were concrete, it is assumed these birds were using the shoreline for roosting or preening although they could also have been feeding on fragments of vegetation within the top water line.

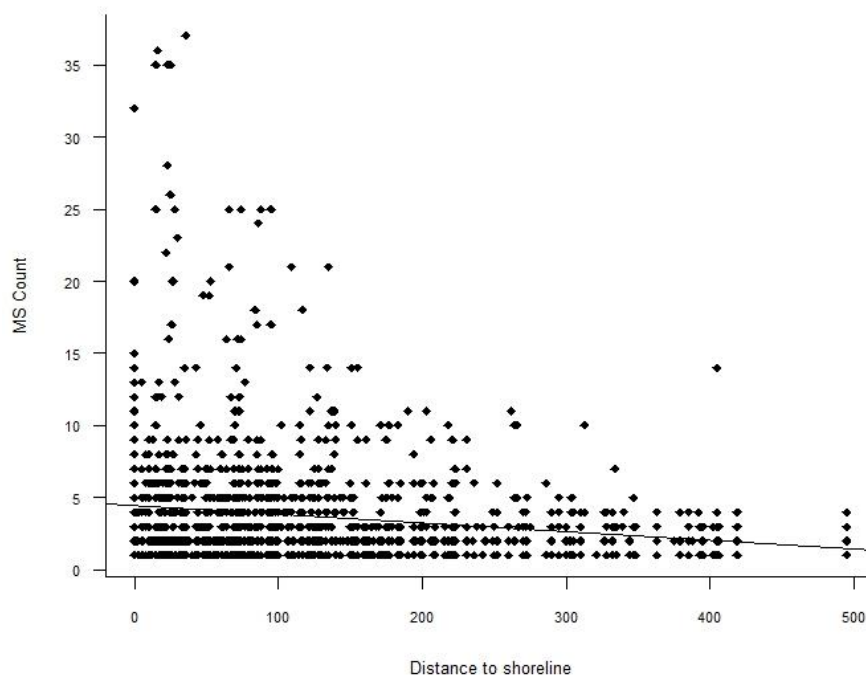


Figure 5.12: The relationship between Mute Swan and distance to shoreline (m) showing high counts directly on or near the shoreline (shown with a regression line (standard linear model $R^2 = 0.02229$, $p < 0.001$)). Similar to other species, the weak relationship (the R^2 value), can be explained by counts of Mute Swan located on the island, Hide Bay and Wigborough Bay when exposed during lower water levels.

5.3.2.9 Great Crested Grebe

Across the four years prior to construction activity Great Crested Grebe at Abberton Reservoir showed a preference for the Main and Western Sections. Within the Main and Central Sections, numbers were highest in 2009 with a total of 248 individuals counted; 154 of these (>60%) occurred in September around Wigborough Bay (Figure 5.13), with smaller aggregations to the east and within Hide Bay. This species is the only piscivore analysed and shows a preference for Refgrid cells

located on the periphery of deeper water. Structural diversity is likely to be maximised in this transitional zone which may provide optimal feeding habitat for this species.

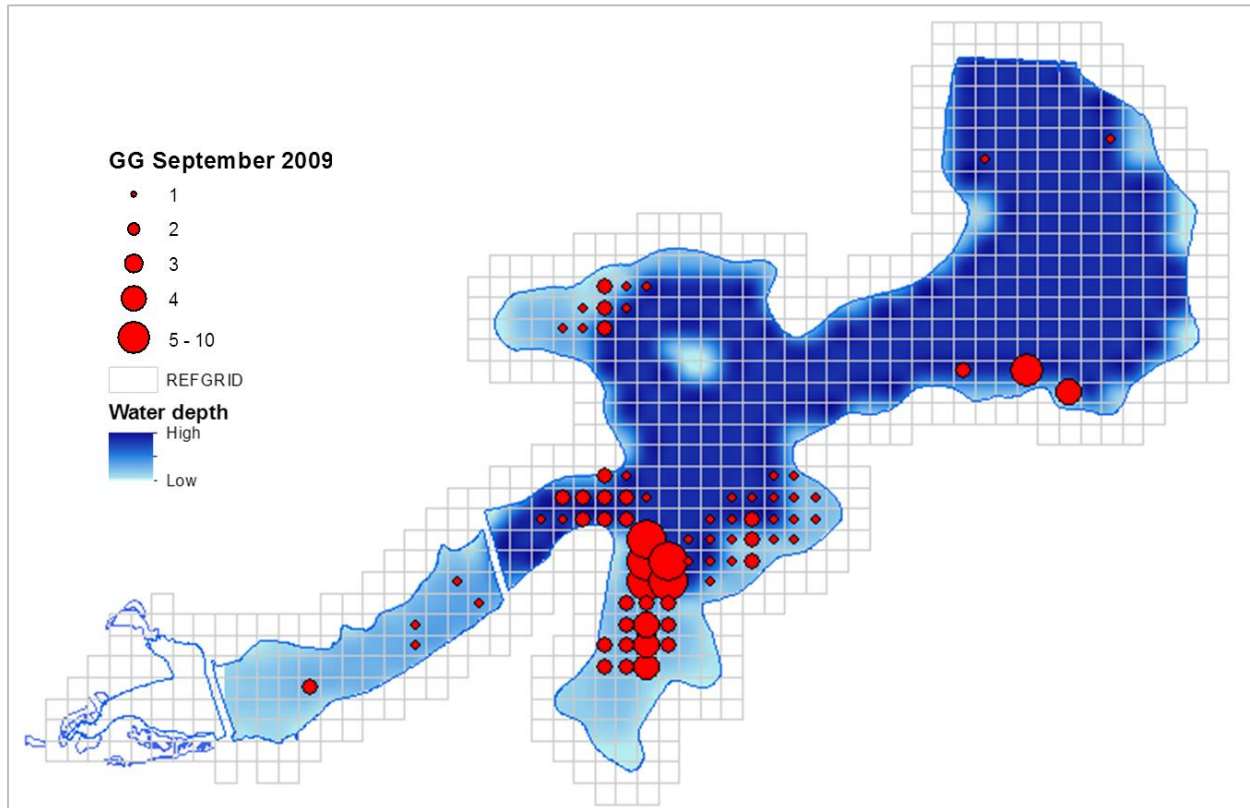


Figure 5.13: Spatial distribution plot of Great Crested Grebe at Abberton Reservoir in September 2009. Water depth is shown as a smoothed DEM.

Hurdle model analysis (Table 5.11) resulted in three variables accounting for numbers of Great Crested Grebe; Section ($\chi^2 = 6.6965$, $df = 14$, $p < 0.01$), temperature ($\chi^2 = 11.121$, $df = 14$, $p < 0.001$) and total rainfall ($\chi^2 = 12.851$, $df = 14$, $p < 0.001$). All were found to positively influence counts with results supporting spatial observations that this species favoured the Main Section over the Central Section.

Bivariate linear modelling for water depth and distance to shoreline was non-significant although % macrophyte ($\chi^2 = 74.448$, $df = 13$, $p < 0.001$) and the relationship between aquatic vegetation and water depth ($\chi^2 = 86.928$, $df = 12$, $p < 0.001$) was for the Hurdle model. The effect of increasing macrophyte cover positively influenced the chance of a count occurrence, with the effect of water depth decreasing per unit increase in vegetation. Results suggest that areas of Abberton Reservoir

important to this species are those containing macrophyte beds in the transitional zone from shallow to deep water; likely to support an abundance and range of prey species upon which Great Crested Grebes can feed. The Main Section displays habitat complexity not necessarily seen in the Central Section; if this is an important factor for this species it explains the relative absence of them from the smaller water body.

Table 5.11: Summary table of Hurdle model results for Great Crested Grebe in years pre-construction. Only variables with a confidence level of 95% (<0.05) are shown.

Variable	Z value	Significance (p-value)	Relationship
Count model (truncated negative binomial with log link)			
Main Section	2.603	<0.01	+
Temperature	3.348	<0.001	+
Total rainfall	3.567	<0.001	+
Zero hurdle model (binomial with logit link)			
2007	-2.644	<0.01	-
2008	3.982	<0.001	+
2009	2.104	<0.05	+
% macrophyte	7.095	<0.001	+
% macrophyte*water depth	-4.401	<0.001	-

Part B

During construction (years 2010 – 2013)

5.4 Results

5.4.1 Spatial autocorrelation (Moran's I Statistic) summary

Waterfowl distribution analysis from Chapter 4 showed that during construction, for combined months April – September and October – March, all nine SPA species displayed spatial clustering in their distribution across Abberton Reservoir. To further investigate the spatial patterns of each species, Moran's I statistic has been calculated for each month (April – September) across the Main and Central Sections. A summary is presented in Table 5.12.

For all species, the spatial pattern varied across months and between the years with clustered patterns typical of high waterfowl count months i.e. August and September. During August 2013 however, all nine SPA species displayed a random distribution pattern. Species showing a predominantly clustered distribution were Mute Swan, Coot, Tufted Duck and Gadwall and those with a random distribution were Shoveler, Wigeon and Great Crested Grebe. All of the dabbling duck species along with Pochard were absent from at least one monthly count during the construction years while Mute Swan, Great crested, Tufted Duck and Coot were present in all months.

Table 5.12: Results of spatial autocorrelation (Moran's I statistic) for nine Abberton Reservoir SPA species during construction. NA refers to where counts for that month/year were zero.

Year	Month	Spatial autocorrelation pattern (Moran's I statistic)								
		Gadwall	Shoveler	Teal	Wigeon	Coot	Tufted Duck	Pochard	Mute Swan	Great Crested Grebe
2010	April	Clustered	Random	Random	Random	Clustered	Clustered	Clustered	Random	Random
	May	Random	Random	NA	NA	Clustered	Random	NA	Clustered	Clustered
	June	NA	NA	NA	Random	Clustered	Random	NA	Clustered	Random
	July	Clustered	Random	NA	Random	Clustered	Clustered	Random	Clustered	Random
	August	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Random
	September	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered
2011	April	Clustered	Random	Clustered	Clustered	Clustered	Clustered	Random	Clustered	Clustered
	May	Clustered	Random	NA	Random	Clustered	Clustered	Random	Clustered	Random
	June	Random	Clustered	Random	Clustered	Clustered	Random	Random	Clustered	Random
	July	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Random
	August	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered
	September	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered
2012	April	Clustered	Clustered	Clustered	Random	Clustered	Clustered	Random	Clustered	Clustered
	May	Random	Random	NA	NA	Random	Random	NA	Clustered	Clustered
	June	Clustered	Random	Random	Random	Clustered	Clustered	Clustered	Clustered	Random
	July	Clustered	Clustered	Random	Random	Clustered	Clustered	Clustered	Clustered	Clustered
	August	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered
	September	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered
2013	April	Random	Clustered	Random	Random	Random	Random	Random	Random	Random
	May	Clustered	Random	Random	Random	Clustered	Clustered	Random	Clustered	Random
	June	Clustered	Clustered	Random	Clustered	Clustered	Clustered	Random	Clustered	Clustered
	July	Clustered	Random	Clustered	Random	Clustered	Clustered	Clustered	Clustered	Random
	August	Random	Random	Random	Random	Random	Random	Random	Random	Random
	September	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered

5.4.2 Species analysis during construction

5.4.2.1 Gadwall

5.4.2.1.1 Construction and waterfowl distribution mapping

Results from previous analysis (see Chapter 4) have shown that numbers of Gadwall significantly increased during construction compared with years pre-construction and during April – September, significant clusters of Gadwall were observed within all three sections (Main, Central and Western). The Western Section was the displacement/mitigation area therefore here it is considered separate from the other two sections and excluded from analysis (see Section 5.2.1).

Gadwall distribution and magnitude of construction disturbance were mapped for total construction disturbance (DTC1, DTC2 and DTC3), machine based disturbance (DMC1, DMC2, DMC3) and people based disturbance (DPC1, DPC2 and DPC3). Results of the mapping process for Gadwall and total construction disturbance are shown for months of April – June (2010 – 2013) in Figure 5.14 and for the months of July – September (2010 – 2013) in Figure 5.15.

Within the Main and Central Section i.e. sections directly affected by construction activity, Gadwall were mainly situated around the edge of the reservoir and within Hide and Wigborough Bay. During these months, the water depth (shown as a smoothed DEM in Figures 5.14 and 5.15) around the edges of the reservoir, in the bays and around the island was shallow, indicating water depth is an important predictor of this species. Numbers of Gadwall peaked during August and September and were highest during 2011 and lowest in 2013.

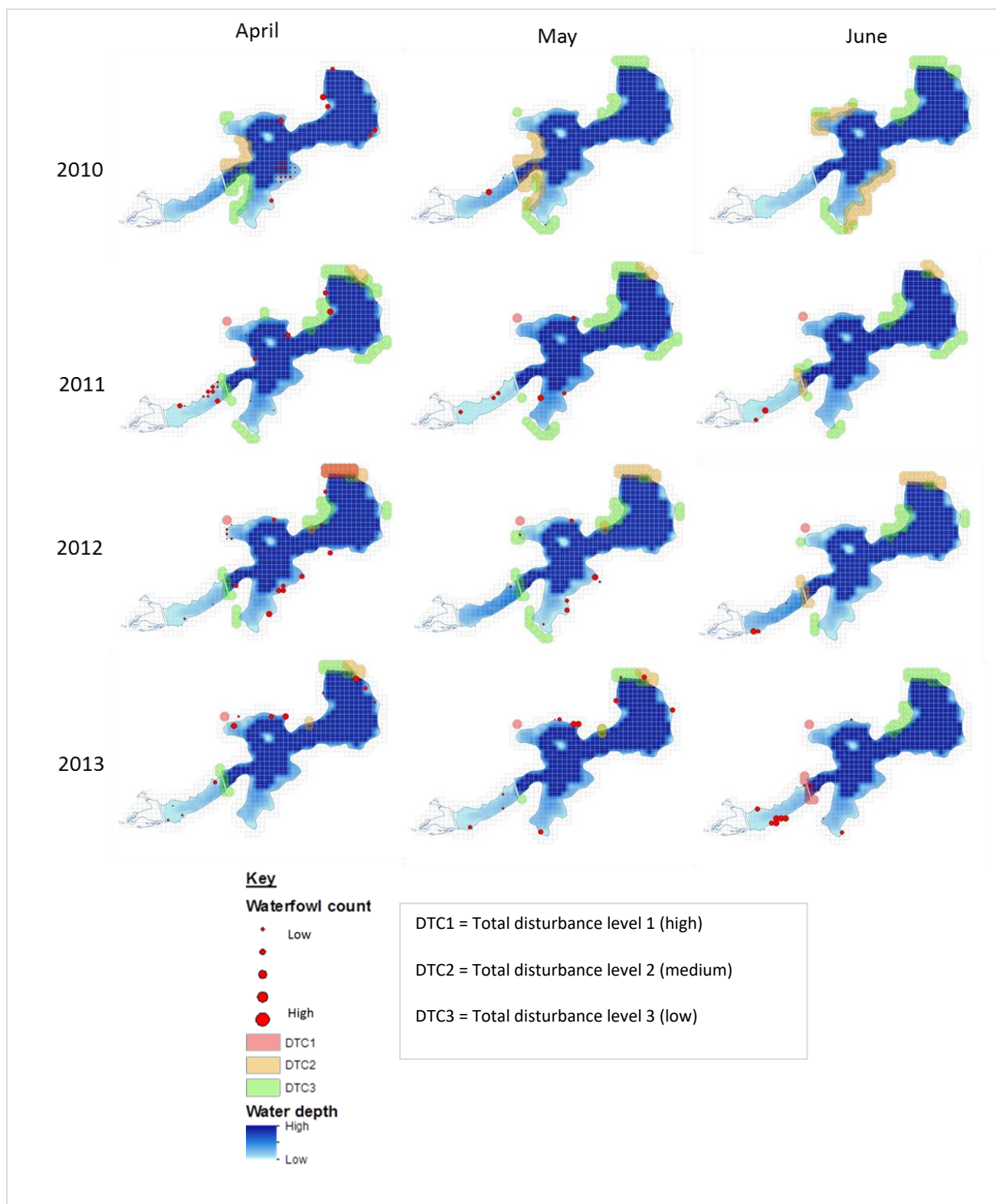


Figure 5.14: Gadwall distribution and extent of construction disturbance for months April, May and June 2010, 2011, 2012 and 2013. Counts vary each month and are represented for visual purposes on a natural breaks (Jenks) classification scale set to 5 classes and defined as low – high counts.

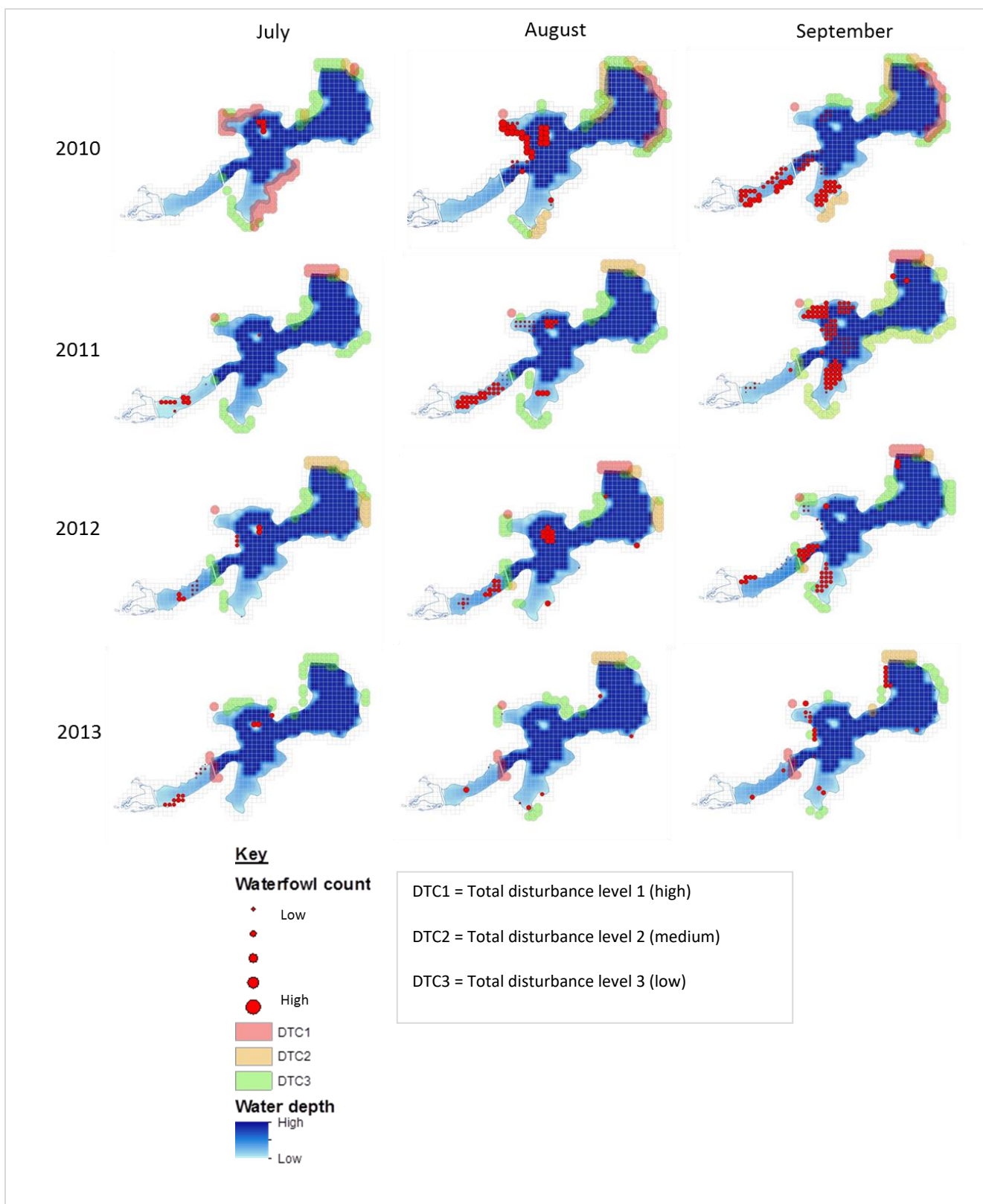


Figure 5.15: Gadwall distribution and extent of construction disturbance for months July, August and September 2010, 2011, 2012 and 2013. Counts vary each month and are represented for visual purposes on a natural breaks (Jenks) classification scale set to 5 classes and defined as low – high counts.

5.4.2.1.2 Statistical analysis

Results from the Hurdle model for Gadwall during construction are presented in Table 5.13. For the count component, year ($\chi^2 = 107.96$, $df = 24$, $p < 0.001$); Section ($\chi^2 = 10.336$, $df = 26$, $p < 0.01$); water depth ($\chi^2 = 18.211$, $df = 26$, $p < 0.01$); temperature ($\chi^2 = 129.46$, $df = 22$, $p < 0.01$); wind speed ($\chi^2 = 125.9$, $df = 22$, $p < 0.001$); % macrophyte ($\chi^2 = 3.6408$, $df = 26$, $p < 0.05$); total rainfall ($\chi^2 = 48.226$, $df = 26$, $p < 0.001$) and the interaction of wind speed and temperature ($\chi^2 = 27.507$, $df = 26$, $p < 0.05$), were all identified as significant environmental predictors of Gadwall. Years 2012, 2013, water depth and the interaction between temperature and wind speed were negative predictors while the effects of 2011, the Main Section, temperature, wind speed, % macrophyte and total rainfall was positive.

Of the construction variables, DTC3 ($\chi^2 = 27.507$, $df = 26$, $p < 0.001$), DMC3 ($\chi^2 = 39.456$, $df = 27$, $p < 0.01$), DPC1 ($\chi^2 = 4.6479$, $df = 26$, $p < 0.05$) and DPC3 ($\chi^2 = 18.81$, $df = 26$, $p < 0.001$), all had a significant positive effect on Gadwall numbers yet DMC2 ($\chi^2 = 5.0904$, $df = 27$, $p < 0.05$), had a negative influence.

The zero component in the Hurdle model is binomial response; a prediction of a zero or a count outcome rather than analysis of numbers of waterfowl. A positive relationship for a zero component variable predicts a count (waterfowl occurrence) outcome, and a negative relationship, a greater chance of a zero observation (Chapter 3). Results show that increasing wind speed, % macrophyte cover and 2012 are all associated with the presence of Gadwall (i.e. a count greater than 0). Similarly, increasing distance to DTC2 and DTC3 is associated with the prediction of a Gadwall occurrence.

Table 5.13: Summary table of Hurdle model results for Gadwall in years during construction. Only variables with a confidence level of 95% (<0.05) are shown (see Appendix 5.2B for further details (applicable for all species)).

Variable	Z value	Significance (p-value)	Relationship
Count model (truncated negative binomial with log link)			
<i>Total construction disturbance</i>			
2011	2.031	<0.05	+
2012	-4.128	<0.001	-
2013	-2.122	<0.05	-
Main section	3.245	<0.001	+
Water depth	-4.284	<0.001	-
Temperature	4.849	<0.001	+
Wind speed	3.714	<0.001	+
% macrophyte	1.915	<0.05	+
Total rainfall	7.158	<0.001	+
Construction (DTC3)	5.407	<0.001	+
Temp*Wind speed	-2.144	<0.05	-
<i>Machine construction disturbance</i>			
Construction (DMC2)	-1.956	<0.05	-
Construction (DMC3)	6.262	<0.01	+
<i>People construction disturbance</i>			
Construction (DPC1)	2.036	<0.05	+
Construction (DPC3)	4.314	<0.001	+
Zero hurdle model (binomial with logit link)			
2012	2.028	<0.05	+
2013	-4.451	<0.001	-
Main section	-5.391	<0.001	-
Water depth	-2.073	<0.05	-
Temperature	-3.802	<0.001	-
Wind speed	3.371	<0.001	+
% macrophyte	6.112	<0.001	+
Total rainfall	-4.197	<0.001	-
Construction (DTC1)	-5.532	<0.001	-
Construction (DTC2)	4.590	<0.001	+
Construction (DTC3)	4.007	<0.001	+
Water depth*% macrophyte	-2.327	<0.05	-
<i>Machine construction disturbance</i>			
Construction (DMC1)	-2.609	<0.01	-
Construction (DMC2)	-3.518	<0.001	-

N.B. Where * indicates an interaction

Part A found that in years pre-construction, water depth was not an important predictor for numbers of Gadwall, but was for the prediction of an occurrence of Gadwall. Results presented here differ and show that water depth during construction was important in terms of presence/absence,

and for numbers of Gadwall which are shown to decrease with increasing water depth. Figure 5.16 illustrates this relationship and shows that higher counts of Gadwall are associated with water depths less than 2m.

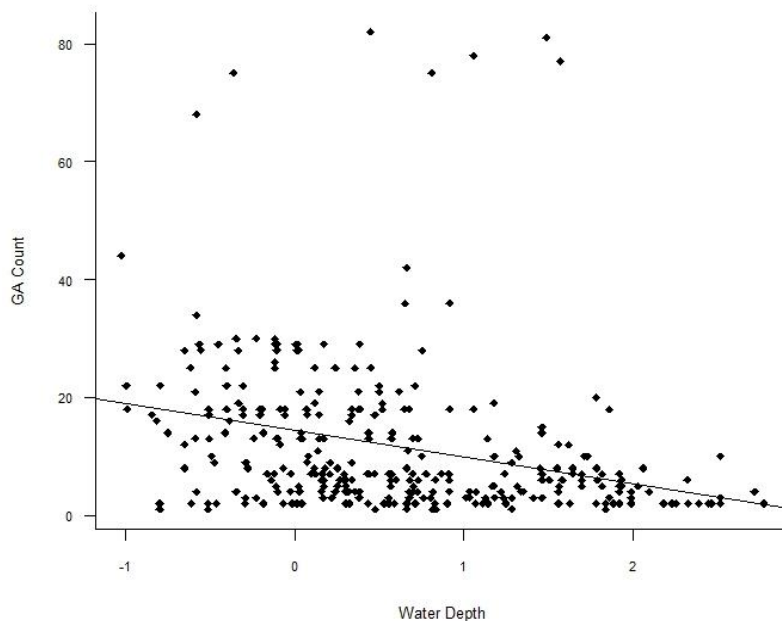


Figure 5.16: The relationship between Gadwall and water depth (m) at Abberton Reservoir (shown with a regression line (standard linear model $R^2 = 0.066$, $p < 0.001$)).

Abberton Reservoir follows a typical waterbody profile in that the shallower water is predominantly closer to the shoreline. What differs however is the presence of shallower areas such as Hide Bay, Wigborough Bay and the island. These are further from the shoreline and become exposed at varying water depths as the water levels are drawn down. The importance of the island to this species is illustrated by Figure 5.17 where a cluster of seven high Gadwall counts (approximately 80 Gadwall in each) are located in Refgrid cells on and around the island.

Although excluded from the Hurdle model (due to collinearity issues) Figure 5.17 also shows that, excluding the bays and island, Gadwall are predominantly located within approximately 200m of the shoreline. This relationship was also observed in years pre-construction however a reduced distance of 100m was associated with the higher numbers of Gadwall (excluding the island). High counts on

the island are the likely cause for the observed weakly positive relationship with distance to shoreline. This is because although at times exposed, the island cannot be considered a constant type of shoreline habitat and is excluded as such.

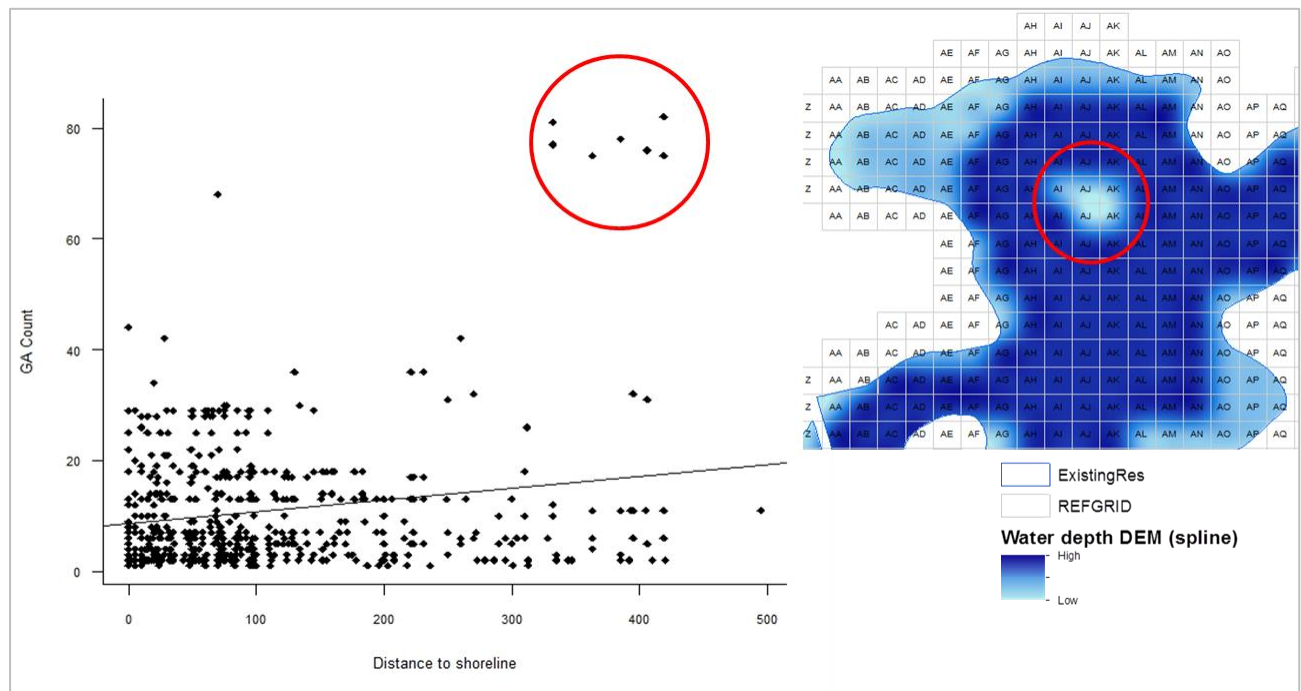


Figure 5.17: The relationship between Gadwall and distance to the shoreline (m) at Abberton Reservoir (shown with a regression line (standard linear model $R^2 = 0.03372$, $p < 0.001$)). The seven high counts highlighted on the left plot are associated with the Refgrid cells on or around the island (highlighted on the map).

Results from the Hurdle model (Table 5.13) show that numbers of Gadwall increased with increasing distance from total, machine and people construction category 3 (the lowest disturbance level) and people disturbance category 1, yet decreased with increasing distance from machine disturbance category 2. Numbers of Gadwall in relation to distance from the nearest source of total construction activity (categories 1, 2 and 3), are shown in Figure 5.18. Plots for machine and people disturbance (for all nine SPA species) are shown in Appendix 5.2B. Results for the construction variables and relationship with Gadwall are somewhat hard to interpret however the size of Abberton Reservoir, dispersed nature, and distance of disturbance events and to the shoreline may explain some of the relationships observed.

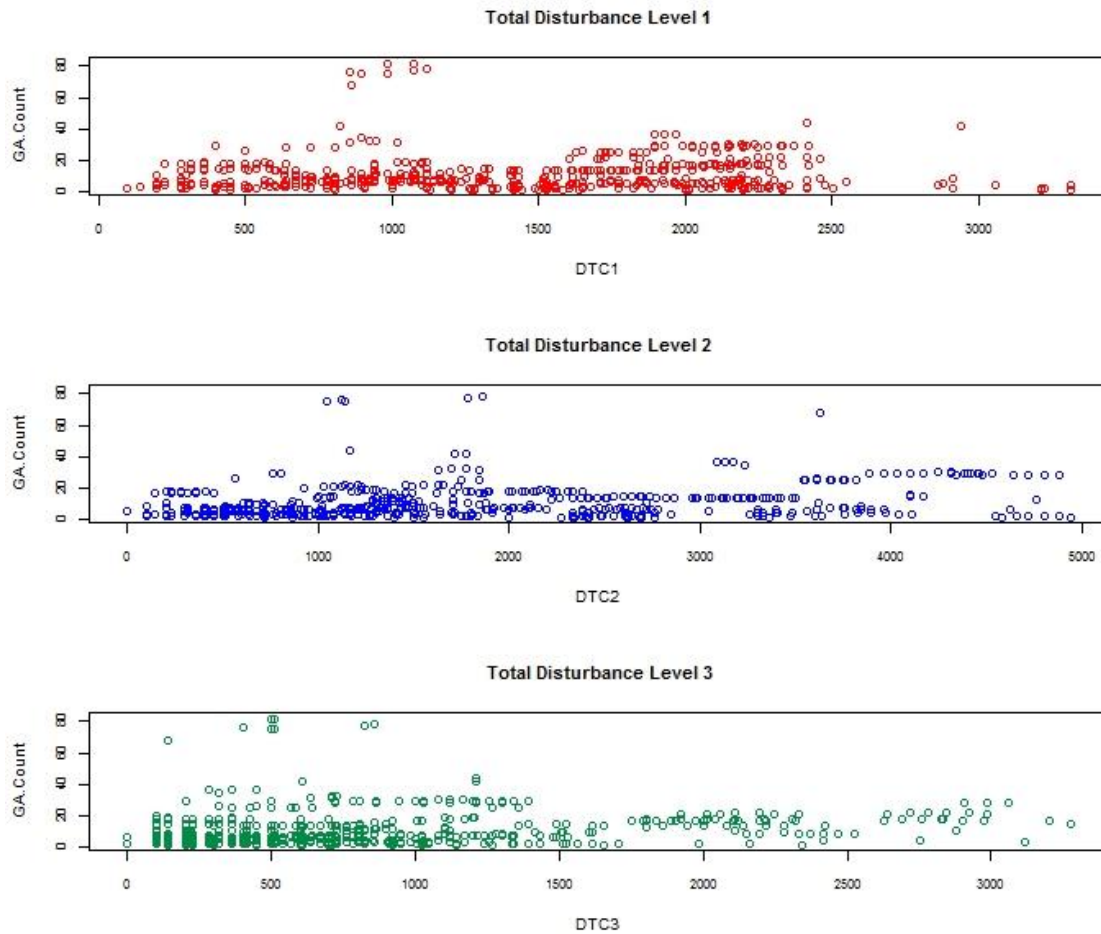


Figure 5.18: Gadwall distribution associated with distance (m) to each total disturbance category (DTC1, DTC2 and DTC3). Note the scales for each category differ.

5.4.2.2 Shoveler

5.4.2.2.1 Construction and waterfowl distribution mapping

Results from Chapter 4 showed that during the months of April – September, numbers of Shoveler were significantly higher at Abberton Reservoir during construction compared with years pre-construction with the increase across the Central Section particularly notable.

Shoveler distribution and magnitude of construction disturbance are mapped for total construction disturbance (DTC1, DTC2 and DTC3), machine based disturbance (DMC1, DMC2, DMC3) and people based disturbance (DPC1, DPC2 and DPC3). Results for total construction are shown for the months of April – June (2010 – 2013) in Figure 5.19 and for the months of July – September (2010 – 2013) in

Figure 5.20. Numbers of Shoveler were highest during August and September (for months April – September) with birds mainly situated within the Central Section during August and in Hide and Wigborough Bay during September. Results from spatial autocorrelation analysis showed that Shoveler, along with all other waterfowl species had a random distribution during August 2013. The spatial pattern during this time is different to that of previous years with Figure 5.20 also highlighting a lack of Shoveler during this month/year.

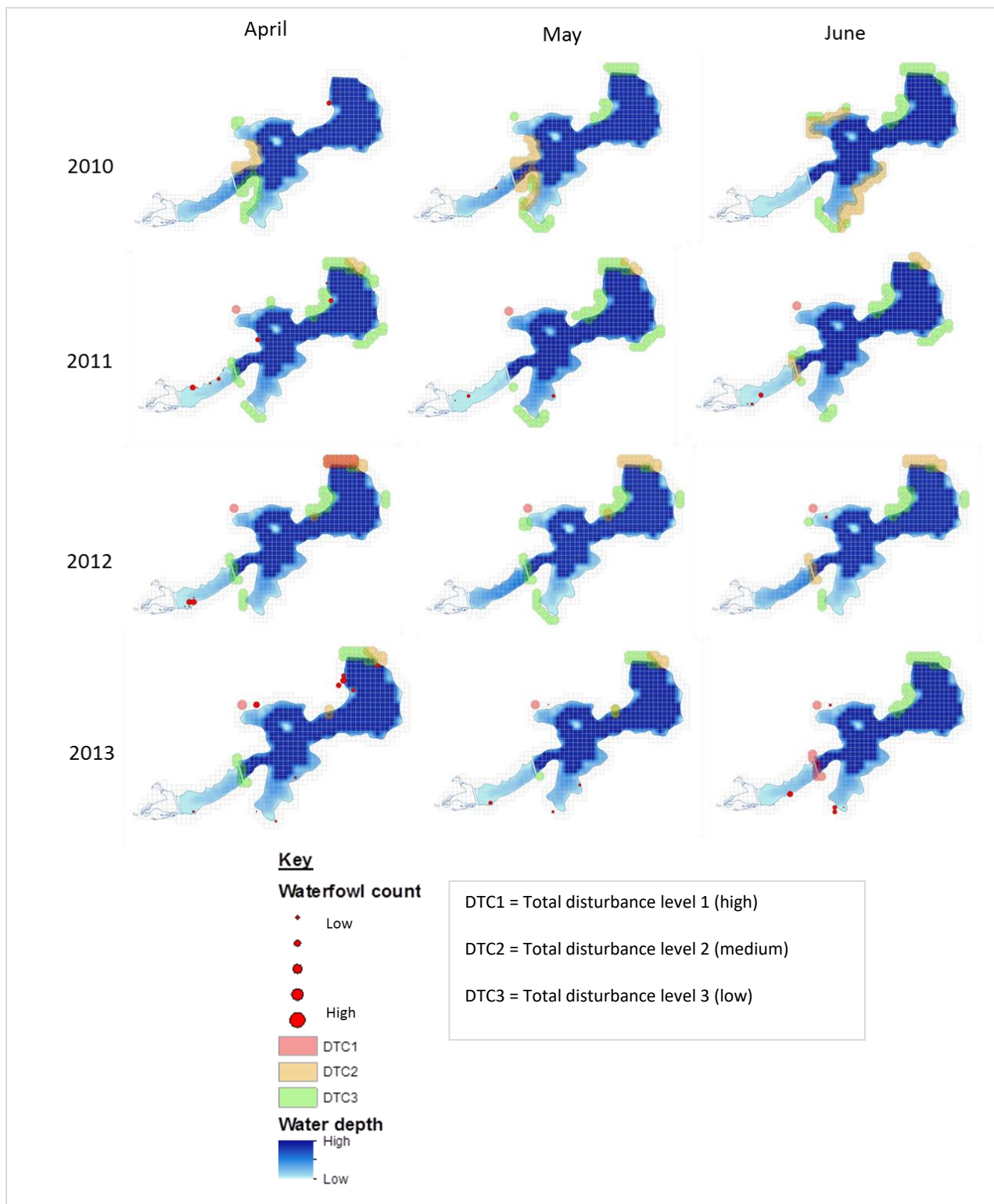


Figure 5.19: Shoveler distribution and extent of construction disturbance for months April, May and June 2010, 2011, 2012 and 2013. Counts vary each month and are represented for visual purposes on a natural breaks (Jenks) classification scale set to 5 classes and defined as low – high counts.

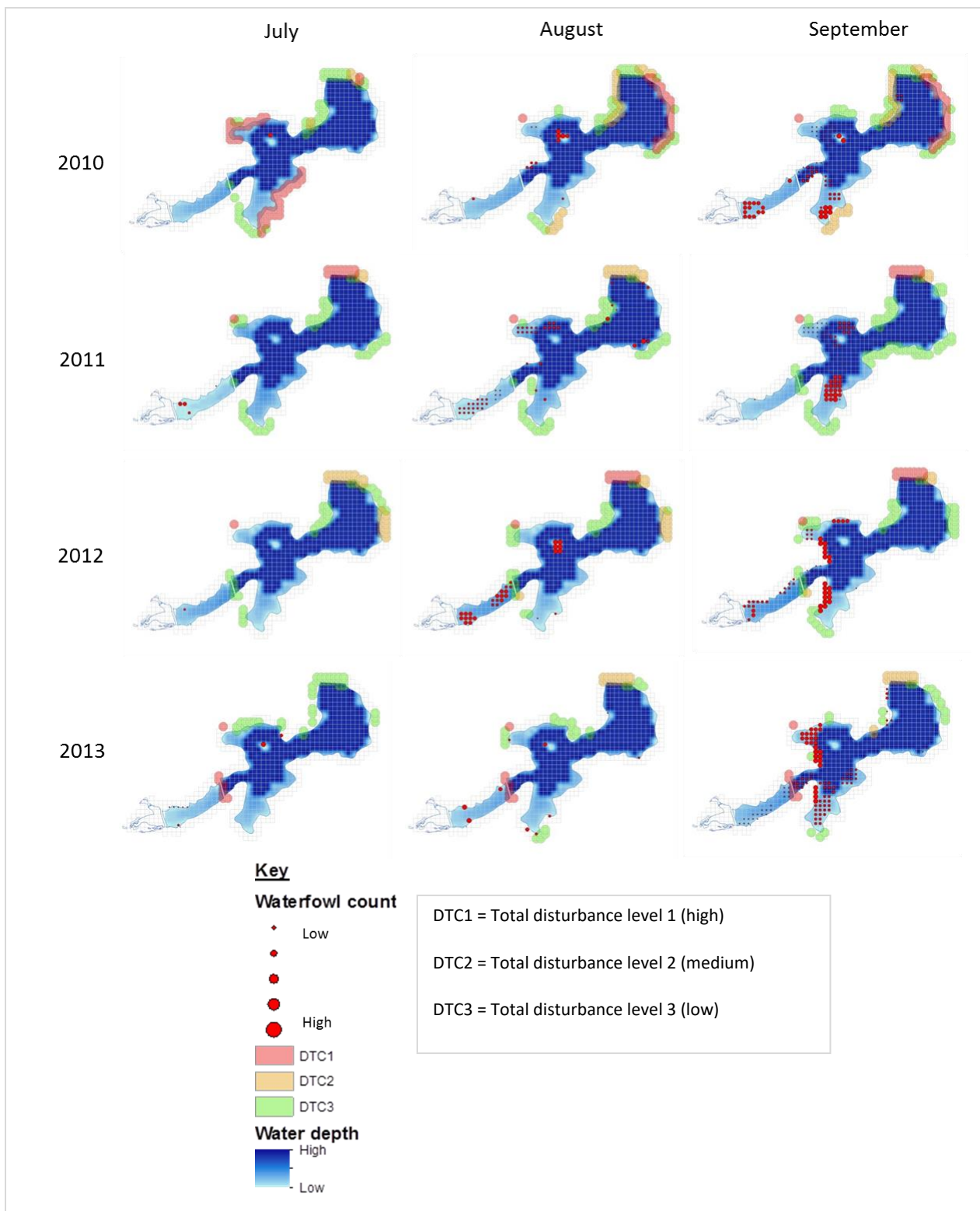


Figure 5.20: Shoveler distribution and extent of construction disturbance for months July, August and September 2010, 2011, 2012 and 2013. Counts vary each month and are represented for visual purposes on a natural breaks (Jenks) classification scale set to 5 classes and defined as low – high counts.

5.4.2.2.2 Statistical analysis

Results from the Hurdle model for Shoveler during construction are presented in Table 5.14. For the count component, year ($\chi^2 = 59.087$, $df = 21$, $p < 0.001$); Section ($\chi^2 = 73.14$, $df = 23$, $p < 0.001$); water depth ($\chi^2 = 7.6623$, $df = 23$, $p < 0.01$); temperature ($\chi^2 = 14.54$, $df = 23$, $p < 0.001$); wind speed ($\chi^2 = 9.9732$, $df = 23$, $p < 0.001$) and total rainfall ($\chi^2 = 15.49$, $df = 23$, $p < 0.001$) were all found to be significant environmental predictors for this species during construction. 2012, the Main Section and temperature were all positive predictors while the response of numbers of Shoveler to increasing water depth, wind speed and total rainfall was negative.

Of the construction variables, distance to total construction disturbance category 2 ($\chi^2 = 5.9017$, $df = 23$, $p < 0.05$); total disturbance category 3 ($\chi^2 = 10.812$, $df = 23$, $p < 0.001$); machine category 3 ($\chi^2 = 13.047$, $df = 23$, $p < 0.001$) and people disturbance category 1 ($\chi^2 = 5.7776$, $df = 25$, $p < 0.05$) were all found to have a positive effect on Shoveler. The effect of machine disturbance category 2 ($\chi^2 = 11.924$, $df = 26$, $p < 0.001$) was negative.

Results from the zero hurdle component found that years 2011, 2012 and 2013 were associated with the prediction of a count outcome. This suggests that numbers of Shoveler were low in 2010 or that during these 'positive' years Shoveler were densely aggregated and occupied less Refgrid cells. Increasing macrophyte cover, distance to machine disturbance category 3 and the effect of an interaction between temperature and total rainfall were also found to be associated with the prediction of a Shoveler occurrence. Construction covariates associated with an increased chance of a zero observation and therefore no waterfowl (a negative relationship is observed) are increasing distance to total construction category 1 and machine and people categories 2 and 3. Negative relationships are also observed for the Main Section, water depth, temperature and rainfall.

Table 5.14: Summary table of Hurdle model results for Shoveler in years during construction. Only variables with a confidence level of 95% (<0.05) are shown.

Variable	Z value	Significance (p-value)	Relationship
Count model (truncated negative binomial with log link)			
<i>Total construction disturbance</i>			
2012	3.26	<0.001	+
Main Section	9.469	<0.001	+
Water depth	-2.754	<0.01	-
Temperature	3.730	<0.001	+
Wind speed	-3.197	<0.001	-
Total rainfall	-4.005	<0.001	-
Construction (DTC1)	2.529	<0.01	+
Construction (DTC3)	3.711	<0.001	+
<i>Machine construction disturbance</i>			
Construction (DMC2)	-3.289	<0.001	-
Construction (DMC3)	3.819	<0.001	+
<i>People construction disturbance</i>			
Construction (DPC1)	2.255	<0.05	+
Zero hurdle model (binomial with logit link)			
2011	2.441	<0.01	+
2012	3.422	<0.001	+
2013	3.107	<0.001	+
Main section	-7.768	<0.001	-
Water depth	-8.332	<0.001	-
Temperature	-7.788	<0.001	-
Macrophyte %	7.279	<0.001	+
Total rainfall	-4.854	<0.001	-
Construction (DTC1)	-8.648	<0.001	-
Temperature * total rainfall	4.179	<0.001	+
<i>Machine construction disturbance</i>			
Construction (DMC1)	-4.702	<0.001	-
Construction (DMC2)	-8.331	<0.001	-
Construction (DMC3)	2.256	<0.05	+
<i>People construction disturbance</i>			
Construction (DPC1)	-12.772	<0.001	-
Construction (DPC2)	-2.116	<0.05	-

N.B. Where * indicates an interaction

Analysis pre construction found years 2008 and 2009 to be the only significant predictors on numbers of Shoveler and a zero count prediction associated with the deeper water and the Main Section. Compared to pre-construction, the relationship with water depth in years during construction increased with the presence of, and numbers of Shoveler associated with shallower

water (Figure 5.21). Additionally, the distribution of this species changed during construction with both presence and numbers of Shoveler associated with the Main Section.

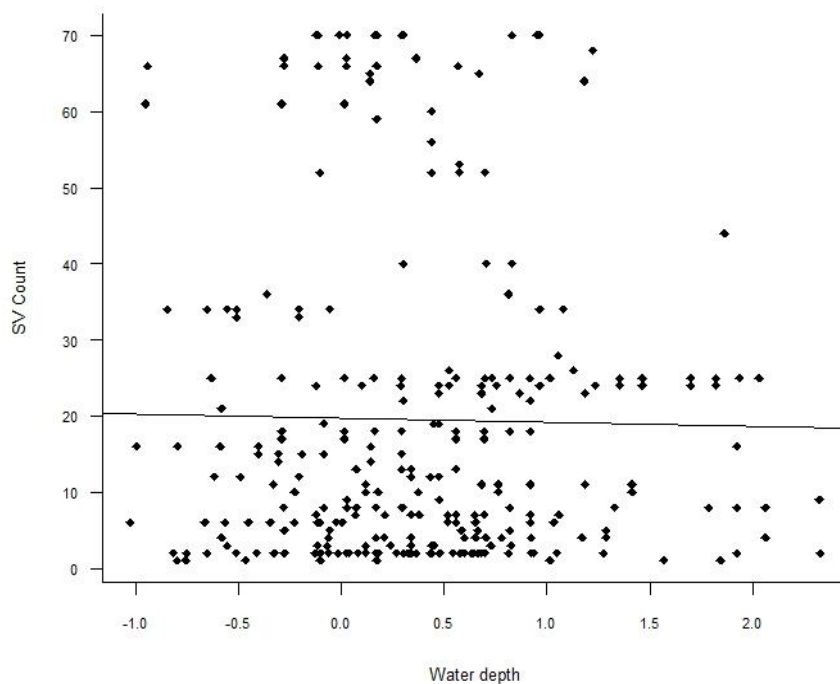


Figure 5.21: The relationship between Shoveler and water depth (m) at Abberton Reservoir (shown with a regression line (standard linear model – non significant ($p > 0.05$) however this variable is a significant predictor in the Hurdle model)).

Pre-construction, Shoveler were also found to have a preference for the island and excluding this feature, were mainly located within 200m of the shoreline. This relationship in years during construction was less obvious and whilst clusters of birds are shown within 200m, the weak relationship is due to high counts located up to 400m from the shoreline (Figure 5.22). It is also apparent from comparing both shoreline distance plots (pre and during construction), that higher numbers and also higher count occurrences were observed in years during construction.

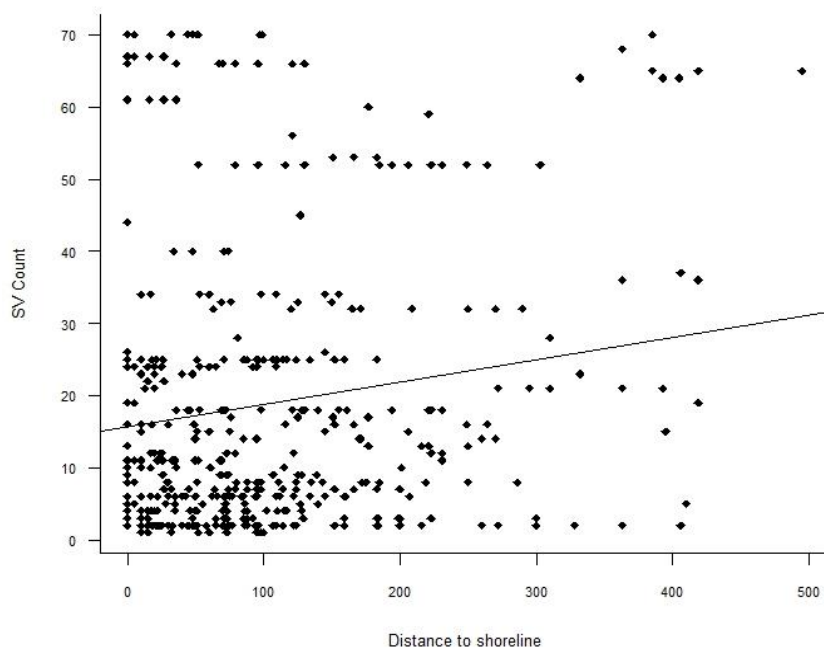


Figure 5.22: The relationship between Shoveler and distance to shoreline (m) at Abberton Reservoir (shown with a regression line (standard linear model $R^2 = 0.022$, $p < 0.001$)).

Analysis shows a positive association with numbers of Shoveler to distance from total disturbance categories 1 and 3, machine disturbance 3 and people disturbance 1. The relationship with total disturbance is shown in Figure 5.23 and together with Figure 5.22 above suggests that Shoveler will locate themselves away from the immediate vicinity (a few hundred metres) of disturbance. This distance also appears to be more pronounced for the higher disturbance categories.

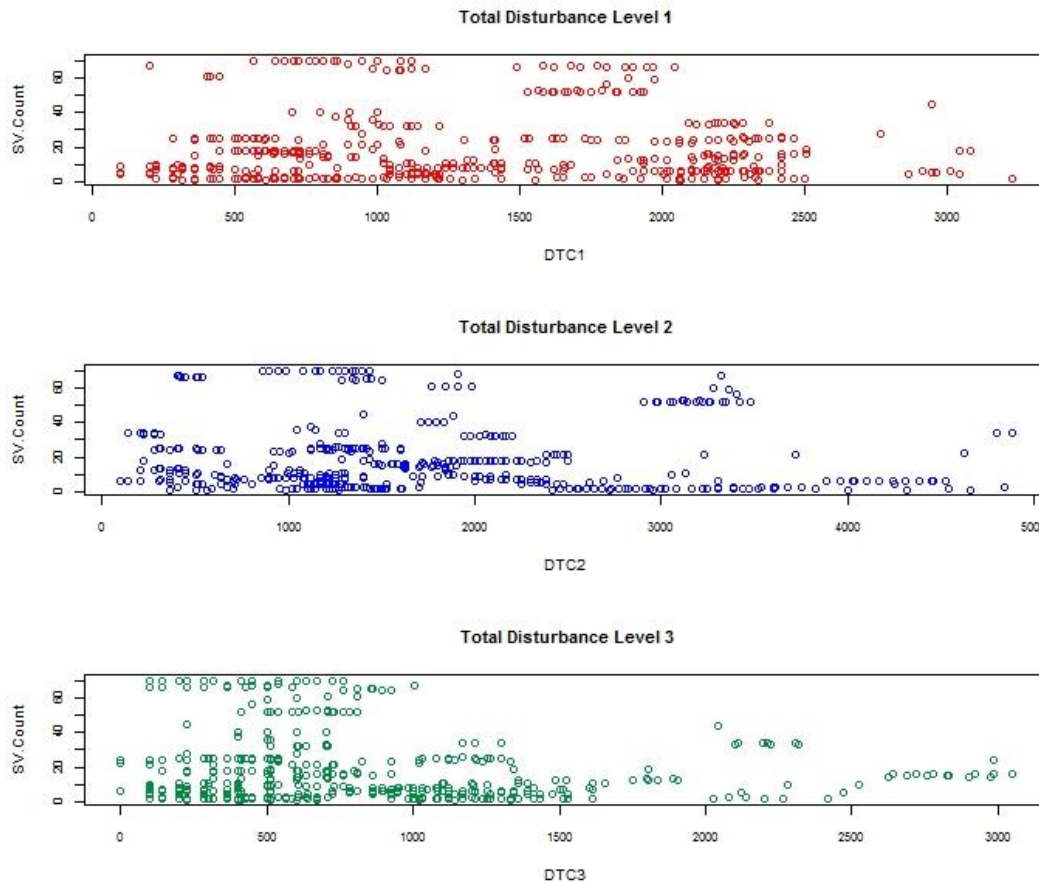


Figure 5.23: Shoveler distribution associated with distance (m) to each total disturbance category (DTC1, DTC2 and DTC3). Note the scales for each category differ.

5.4.2.3 Teal

5.4.2.3.1 Construction and waterfowl distribution mapping

Peak counts of Teal were typically observed during August and September and typical of flocking species (with the exception of August 2013); a clustered pattern dominates the higher count months. Previous analysis from Chapter 4 showed that within the Central and Main Sections i.e. sections directly affected by construction activity, Teal pre-construction were found to favour the Central Section and also, particularly during the months of August and September, the areas associated with Hide and Wigborough Bay. During these months, and for all years, the water depth around the edges of the reservoir and within these bays is typically shallow indicating water depth is an important predictor of this species. Indeed, Part A found that this species in years pre-

construction were negatively associated with increasing water depths and showed a preference for areas close to the shoreline.

Teal distribution and the magnitude of construction disturbance were mapped and results for total construction shown for months of April – June (2010 – 2013), in Figure 5.24 and for the months of July – September (2010 – 2013), in Figure 5.25. These figures initially suggest that disturbance may have had a negative impact as Teal are largely absent from areas with a high extent of shoreline construction activity i.e. the north-east areas; however data investigation has shown that this is not a preferred area for the species regardless of the month or year. The clustered distribution of Teal near the western extent of the Main Section during September 2013 is more pronounced than in other years and is also observed for other species. A preference for this location/avoidance of other areas may be a result of disturbance displacement or possibly an environmental condition such as a strong wind.

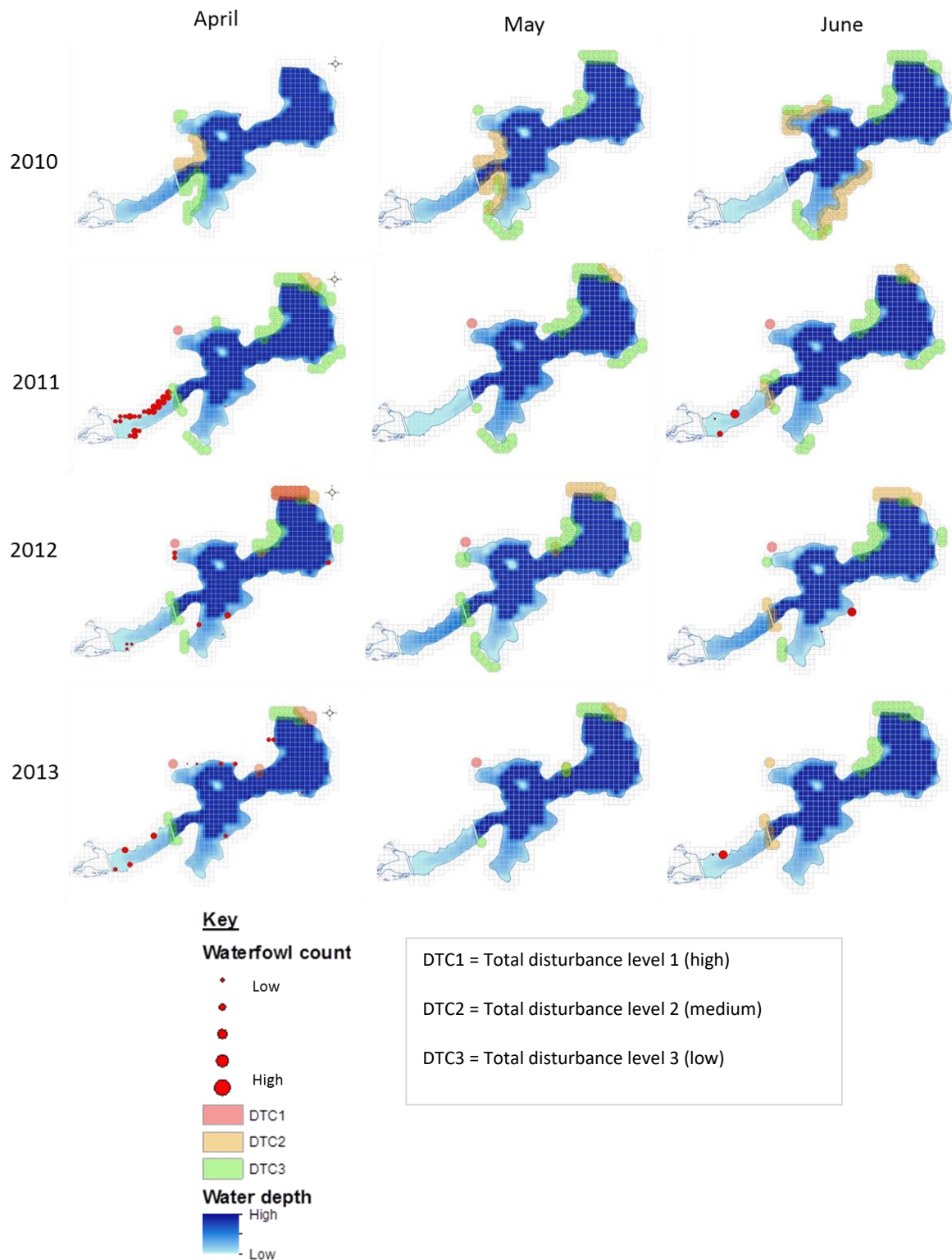


Figure 5.24: Teal distribution and extent of construction disturbance for months April, May and June 2010, 2011, 2012 and 2013. Counts vary each month and are represented for visual purposes on a natural breaks (Jenks) classification scale set to 5 classes and defined as low – high counts.

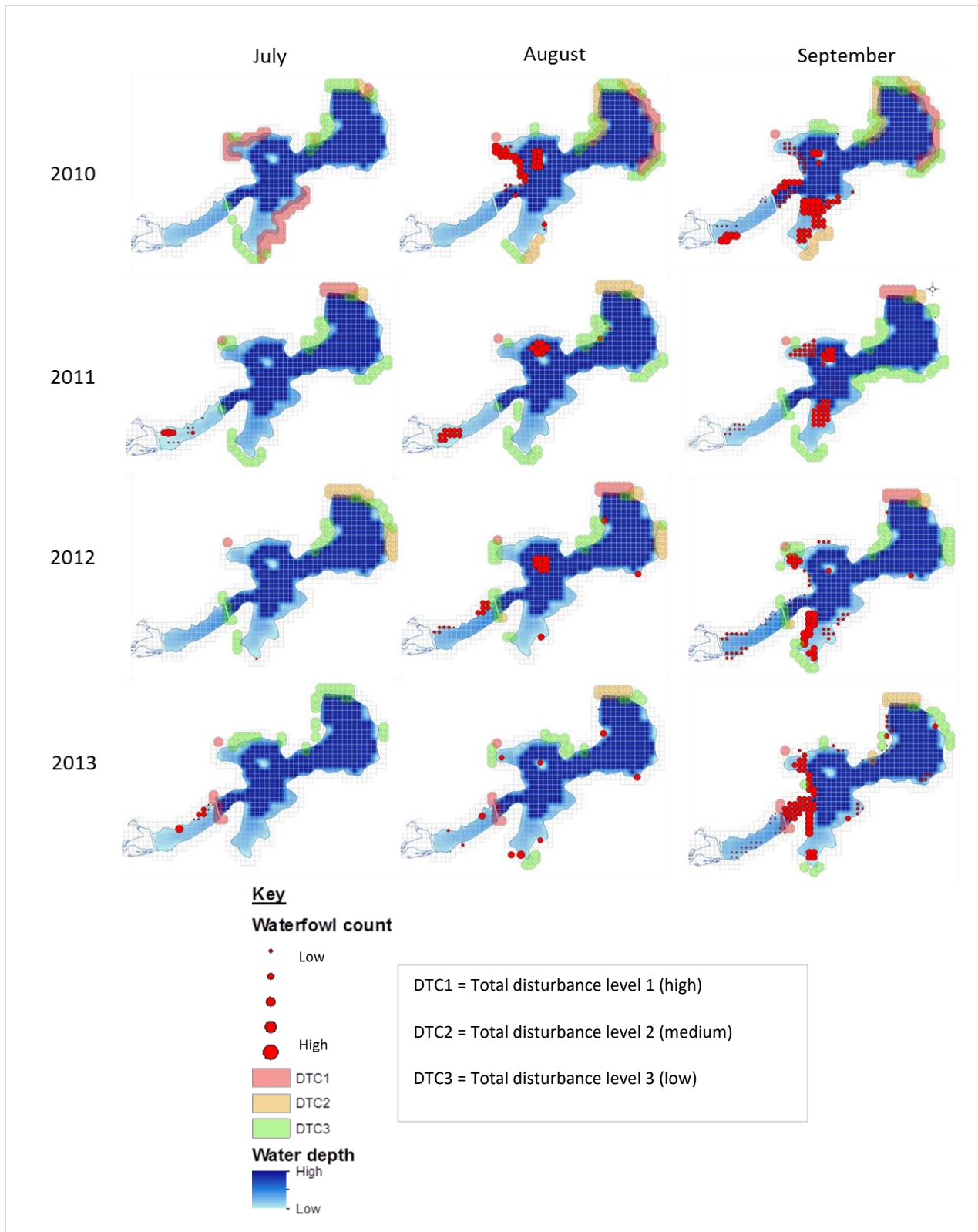


Figure 5.25: Teal distribution and extent of construction disturbance for months July, August and September 2010, 2011, 2012 and 2013. Counts vary each month and are represented for visual purposes on a natural breaks (Jenks) classification scale set to 5 classes and defined as low – high counts.

5.4.2.3.2 Statistical analysis

Results from the Hurdle model (Table 5.15), show that for the Teal count model, the environmental covariates year ($\chi^2 = 12.007$, $df = 22$, $p < 0.01$); Section ($\chi^2 = 87.1950$, $df = 24$, $p < 0.001$); water depth ($\chi^2 = 7.1646$, $df = 24$, $p < 0.01$) and the interaction between temperature and wind speed ($\chi^2 = 7.1861$, $df = 24$, $p < 0.01$) were all influential on counts of Teal. The effect of the Main Section was positive i.e. Teal during construction were observed in higher numbers compared with the Central Section while 2011, 2012, 2013 (compared to 2010) and increasing water depth, all had a negative effect on Teal numbers. Total construction category 1 ($\chi^2 = 11.438$, $df = 24$, $p < 0.001$), machine construction category 1 (χ^2 could not be calculated) and people construction category 1 ($\chi^2 = 5.9744$, $df = 19$, $p < 0.01$) were negative predictors yet the effect of distance to total construction category 3 ($\chi^2 = 6.1741$, $df = 24$, $p < 0.01$) was positive.

Significant predictors on a zero count outcome include year ($\chi^2 = 30.556$, $df = 22$, $p < 0.001$) for which the relationship during 2012 and 2013 was positive (higher likelihood of a Teal count), and 2011 which was negative (higher likelihood of a zero count). 2011 was also a negative predictor for numbers of Teal yet 2010 and 2011 had the highest numbers of this species observed during the four years with counts of 3928 and 3421 respectively. These results appear conflicting however, spatial mapping shows that although in years during construction Teal favoured the Main Section; during 2011 specifically, they were observed in higher numbers within the Central Section and in the Main Section were aggregated in dense clusters. This accounts for the results reported.

Other environmental covariates influencing a zero Teal count prediction were % macrophyte cover ($\chi^2 = 28.849$, $df = 23$, $p < 0.001$); water depth ($\chi^2 = 127.8$, $df = 23$, $p < 0.001$); temperature ($\chi^2 = 106.17$, $df = 23$, $p < 0.001$); wind speed ($\chi^2 = 61.46$, $df = 23$, $p < 0.001$); total rainfall ($\chi^2 = 46.557$, $df = 24$, $p < 0.001$) and the interaction between water depth and % macrophyte (χ^2 could not be calculated). Of these, only increasing % macrophyte cover was shown to significantly increase the chance of a count outcome with all other variables associated with the prediction of a zero count.

The significant relationship of the interaction means that as water depth increases, the effect of increasing % macrophyte decreases showing that both these variables are important for the prediction of a Teal observation. Of the construction variables, distance to construction categories DTC2 (χ^2 calculation error), DTC3 ($\chi^2 = 44.564$, $df = 24$, $p < 0.001$) and DMC3 ($\chi^2 = 22.85$, $df = 23$, $p < 0.001$) were all associated with an increased chance of a count outcome. Distance to DTC1 ($\chi^2 = 23.198$, $df = 24$, $p < 0.001$), DMC2 (χ^2 calculation error) and DPCI ($\chi^2 = 95.153$, $df = 19$, $p < 0.001$) however, all had a negative influence and are associated with the prediction of a zero count observation.

Table 5.15: Summary table of Hurdle model results for Shoveler in years during construction. Only variables with a confidence level of 95% (< 0.05) are shown.

Variable	Z value	Significance (p-value)	Relationship
Count model (truncated negative binomial with log link)			
<i>Total construction disturbance</i>			
2011	-2.233	<0.05	-
2012	-2.418	<0.05	-
2013	-3.214	<0.001	-
Main Section	10.034	<0.001	+
Water depth	-3.916	<0.001	-
Construction (DTC1)	-3.326	<0.001	-
Construction (DTC3)	2.677	<0.01	+
Temperature*wind speed	2.727	<0.01	+
<i>Machine construction disturbance</i>			
Construction (DMC1)	-3.560	<0.001	-
<i>People construction disturbance</i>			
Construction (DPCI)	-6.097	<0.001	-
Zero hurdle model (binomial with logit link)			
2011	-2.217	<0.05	-
2012	2.011	<0.05	+
2013	1.944	<0.05	+
Water depth	-6.807	<0.001	-
Temperature	-9.452	<0.001	-
Wind speed	-7.366	<0.001	-
% macrophyte	5.295	<0.001	+
Total rainfall	-6.416	<0.001	-
Construction (DTC1)	-6.072	<0.001	-
Construction (DTC2)	4.784	<0.001	+
Construction (DTC3)	6.612	<0.001	+
Water depth*% macrophyte	-2.637	<0.01	-

<i>Machine construction disturbance</i>			
Construction (DMC2)	-7.801	<0.001	-
Construction (DMC3)	4.962	<0.001	+
<i>People construction disturbance</i>			
Construction (DPC1)	-12.958	<0.001	-

N.B. Where * indicates an interaction

Results from Hurdle model and spatial analysis show that for Teal at Abberton Reservoir, water depth is a key environmental predictor. Figure 5.26 shows the negative association with increasing water depth with Teal predominantly preferring areas with a water depth below one metre.

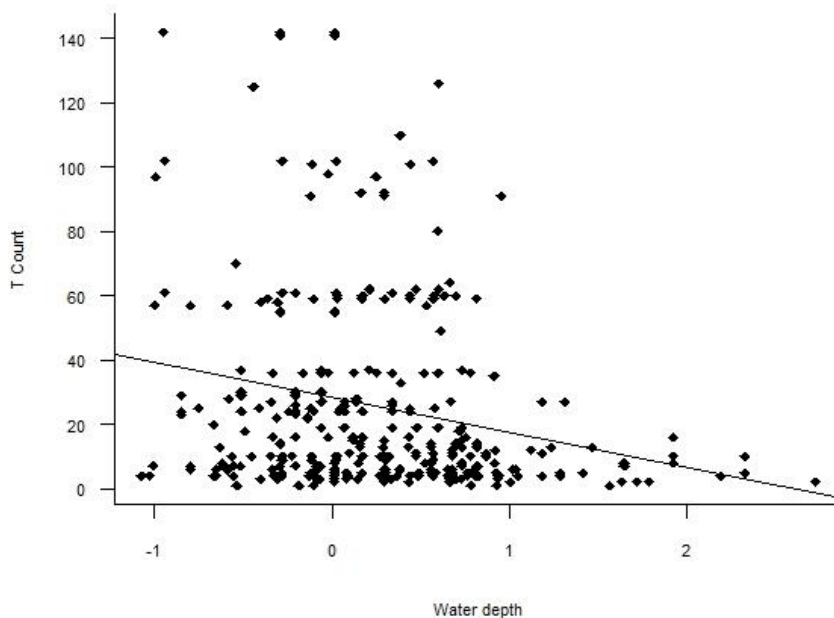


Figure 5.26: The relationship between Teal and water depth (m) at Abberton Reservoir (shown with a regression line (standard linear model $R^2 = 0.049$, $p < 0.001$).

The relationship between Teal and distance to construction activity showed total, machine and people disturbance categories 1 were all negative predictors while total disturbance categories 2, 3 and machine disturbance category 3 were positive. On initial assessment this suggests that Teal respond favourably to construction disturbance with numbers decreasing with increasing distance from high magnitude disturbance events. Figure 5.27 shows the occurrence of teal and distance to the nearest construction event for all three categories of total disturbance. The distance from

construction varies and given the size of Abberton, the values are large however the majority of Teal are between 200m and 2000m. This distance is slightly increased for higher disturbance categories (i.e. DTC1, DMC1 and DPC1). See Appendix 5.2B for machine and people plots.

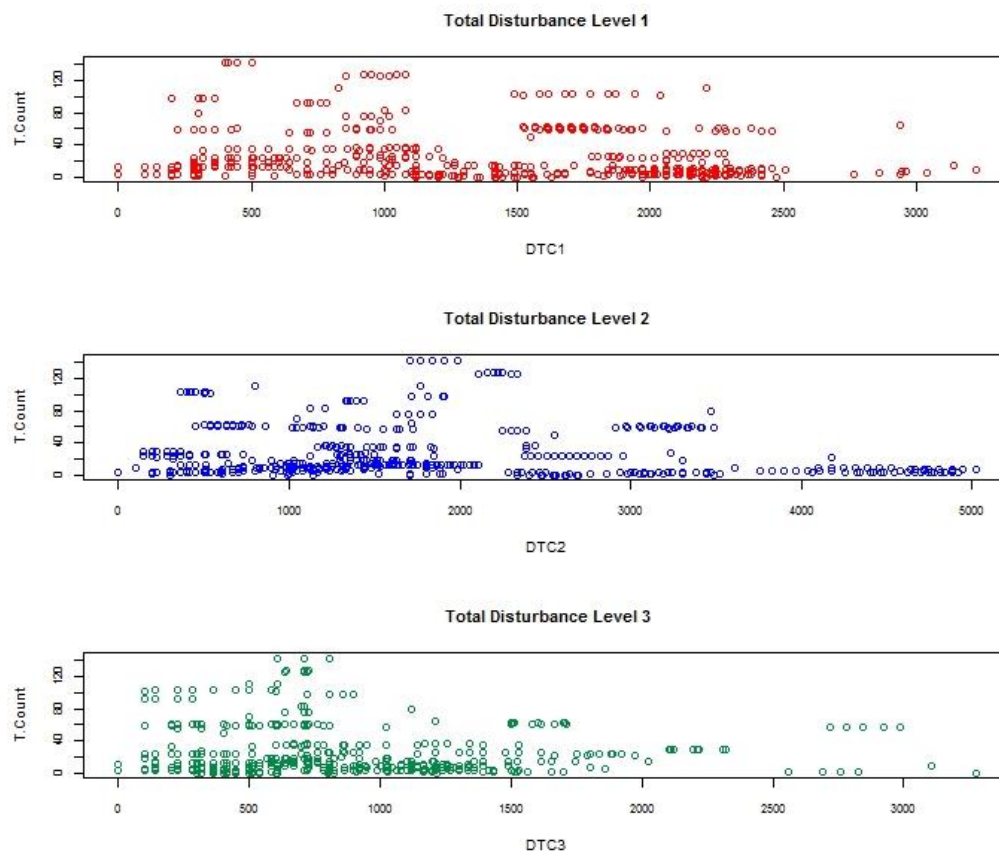


Figure 5.27: Teal distribution associated with distance (m) to each total disturbance category (DTC1, DTC2 and DTC3).

Teal have been shown to prefer a shallow water depth which at Abberton Reservoir, occurs at distances closer to the shoreline. This association may explain the occurrence of Teal being located closer to disturbance events (Table 5.15 and Figure 5.27 above). The relationship with water depth also explains the high numbers of Teal observed at large distances from the shoreline (Figure 5.28) because the majority of these occurrences are located on or around the island; exposed at lower water levels.

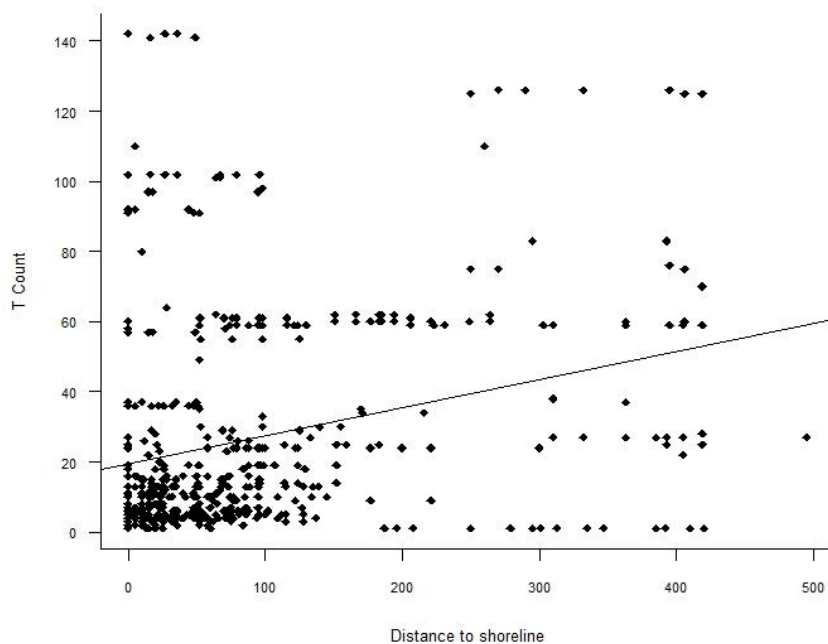


Figure 5.28: The relationship between Teal and distance to shoreline (m) at Abberton Reservoir (shown with a regression line (standard linear model $R^2 = 0.073$, $p < 0.001$)).

5.4.2.4 Wigeon

5.4.2.4.1 Construction and waterfowl distribution mapping

Numbers of Wigeon at Abberton Reservoir are typically low for months April through to July increasing substantially during August and September (Figures 5.29 and 5.30). Across the Main and Central Sections during construction, counts were highest in 2010 (1989) with the species showing a preference for the Central Section. In years 2011 and 2013, large aggregations were also seen across Hide Bay. This pattern of spatial distribution was also observed pre-construction with Wigeon mainly located in the Central Section and in 2007 and 2008, the bays within the Main Section. Total numbers of Wigeon across Abberton Reservoir during the months of April – September were found to significantly increase during construction (Chapter 4) suggesting that overall, this species was not deterred from the reservoir complex by construction activity.

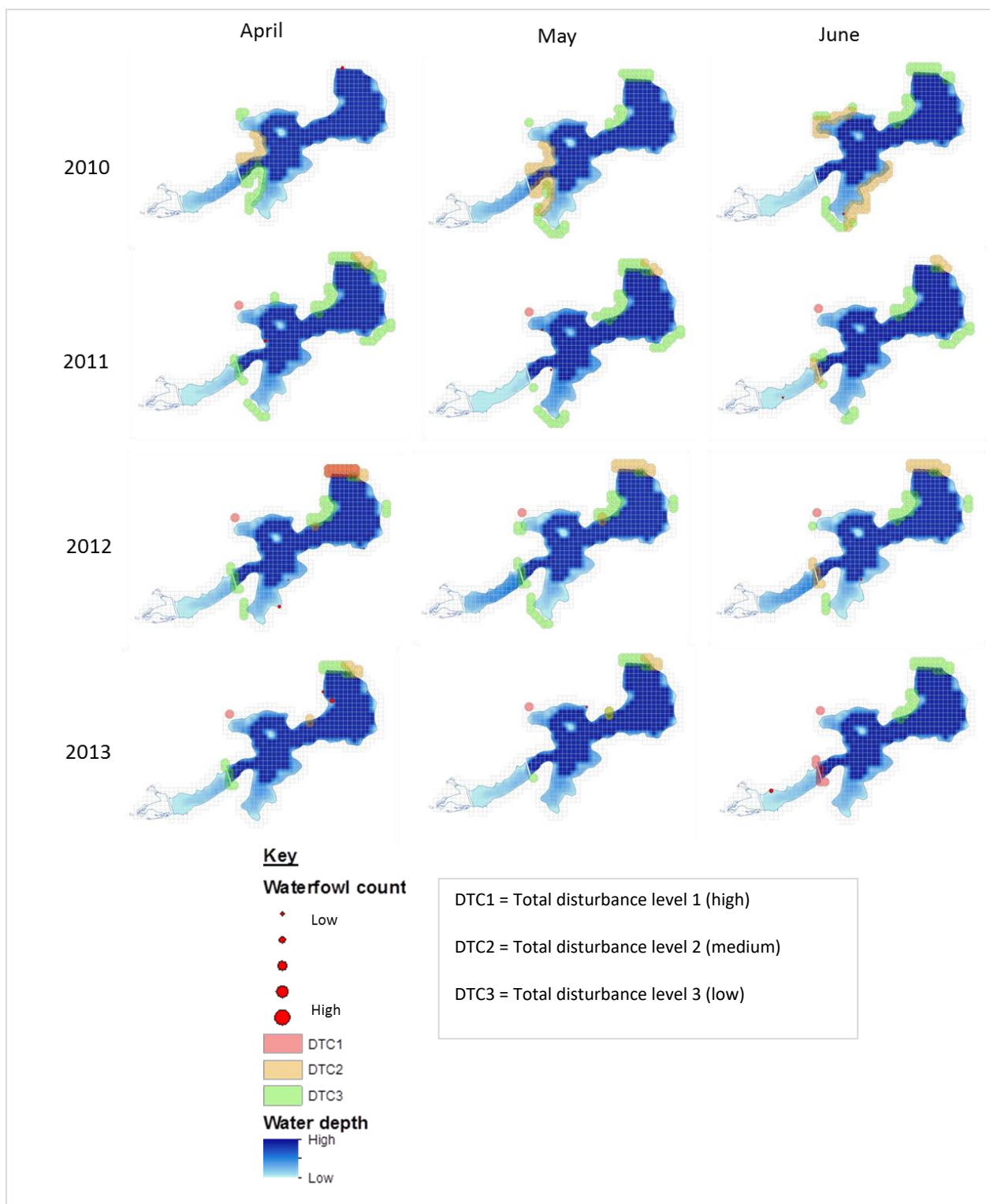


Figure 5.29: Wigeon distribution and extent of construction disturbance for months April, May and June 2010, 2011, 2012 and 2013. Counts vary each month and are represented for visual purposes on a natural breaks (Jenks) classification scale set to 5 classes and defined as low – high counts.

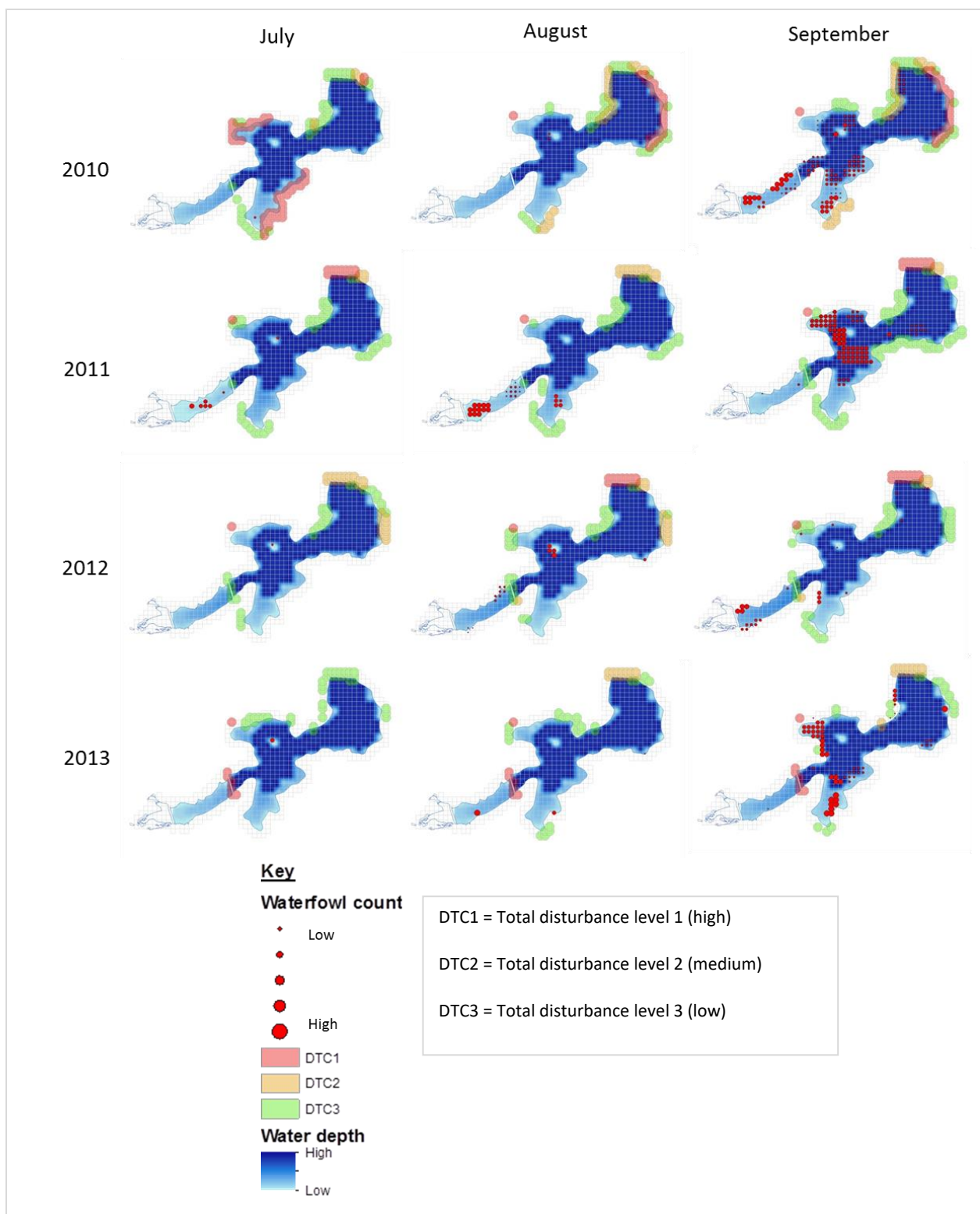


Figure 5.30: Wigeon distribution and extent of construction disturbance for months July, August and September 2010, 2011, 2012 and 2013. Counts vary each month and are represented for visual purposes on a natural breaks (Jenks) classification scale set to 5 classes and defined as low – high counts.

5.4.2.4.2 Statistical analysis

To investigate impacts of construction activity and the influence of environmental conditions on Wigeon, Hurdle models were applied to the count data. A summary of the resulting minimal adequate model is presented in Table 5.16 below. Results found that, similarly to years pre-construction (Part A), water depth ($\chi^2 = 388.55$, $df = 20$, $p < 0.001$), is a highly significant predictor for numbers of Wigeon with this species strongly associated with shallower water. The only other negative predictor for numbers of Wigeon is 2011 (year variable $\chi^2 = 9.0813$, $df = 18$, $p < 0.05$), for which counts were lower than 2010. Predictors for the count component and those positively influencing numbers of Wigeon include Section ($\chi^2 = 7.4196$, $df = 20$, $p < 0.001$), with higher numbers observed for the Main Section; distance to total construction category 2 (DTC2) ($\chi^2 = 25.909$, $df = 20$, $p < 0.001$) and distance total construction category 3 ($\chi^2 = 69.401$, $df = 20$, $p < 0.001$). For machine and people disturbance, distance to both categories 2 (machine $\chi^2 = 8.0122$, $df = 18$, $p < 0.001$, people $\chi^2 = 11.214$, $df = 20$, $p < 0.001$) and 3 (machine $\chi^2 = 36.185$, $df = 18$, $p < 0.01$, people $\chi^2 = 24.788$, $df = 20$, $p < 0.001$) were found to be associated with an increase in numbers of Wigeon.

For the zero model component, environmental covariates associated with an increased chance of a Wigeon count (positive relationship observed) are year ($\chi^2 = 20.338$, $df = 18$, $p < 0.001$); temperature ($\chi^2 = 119.19$, $df = 19$, $p < 0.001$); wind speed ($\chi^2 = 39.833$, $df = 19$, $p < 0.001$) and % macrophyte ($\chi^2 = 36.342$, $df = 20$, $p < 0.001$). Higher temperatures are typical of August and September when Wigeon are more abundant and the relationship with % macrophyte was also seen in years pre-construction with the presence of Wigeon associated with aquatic vegetation. The relationship with wind speed is a little harder to interpret since this was found to be a negative predictor for numbers and presence of Wigeon pre-construction. Negative predictors during construction, where a count of zero is more likely are total rainfall ($\chi^2 = 38.911$, $df = 20$, $p < 0.001$), all three total and machine construction variables and distance to people based disturbance categories 1 and 2 (see Appendix 5.2B for

calculated X^2 values). The interaction between increasing temperature and wind speed was also found to be significant with the effect of wind speed decreasing with higher temperatures.

Table 5.16: Summary table of Hurdle model results for Wigeon in years during construction. Only variables with a confidence level of 95% (<0.05) are shown.

Variable	Z value	Significance (p-value)	Relationship
Count model (truncated negative binomial with log link)			
<i>Total construction disturbance</i>			
2011	-2.737	<0.01	-
Main Section	2.647	<0.01	+
Water depth	-2.032	<0.05	-
Construction (DTC2)	4.827	<0.001	+
Construction (DTC3)	9.107	<0.001	+
<i>Machine construction disturbance</i>			
Construction (DMC2)	2.865	<0.001	+
Construction (DMC3)	6.562	<0.001	+
<i>People construction disturbance</i>			
Construction (DPC2)	2.384	<0.001	+
Construction (DPC3)	4.638	<0.05	+
Zero hurdle model (binomial with logit link)			
2011	3.931	<0.001	+
2012	2.703	<0.01	+
2013	3.545	<0.001	+
Temperature	2.663	<0.01	+
Wind speed	6.183	<0.001	+
% macrophyte	6.088	<0.001	+
Total rainfall	-5.759	<0.001	-
Construction (DTC1)	-5.436	<0.001	-
Construction (DTC2)	7.321	<0.001	+
Construction (DTC3)	3.923	<0.001	+
Temperature*wind speed	-5.812	<0.001	-
<i>Machine construction disturbance</i>			
Construction (DMC1)	-4.423	<0.001	-
Construction (DMC2)	-8.941	<0.001	-
Construction (DMC3)	4.972	<0.001	+
<i>People construction disturbance</i>			
Construction (DPC1)	-11.179	<0.001	-
Construction (DPC2)	-3.400	<0.001	-

N.B. Where * indicates an interaction

The finding of numbers of Wigeon increasing with increasing distance away from the lower construction categories suggests disturbance had an impact upon the spatial distribution of this species. However, if this were the case, one would also expect Wigeon to distance themselves from

the most disturbing activities which was not found. In fact, increasing distance from category 1 for total, machine and people based disturbance is associated with the prediction of a zero outcome.

Figure 5.31 shows the distances of Wigeon to DTC1, DTC2 and DTC3 and although non-significant in the Hurdle model, it appears that, similarly to other species; lower Wigeon counts are observed within Refgrid cells closest to the higher categories.

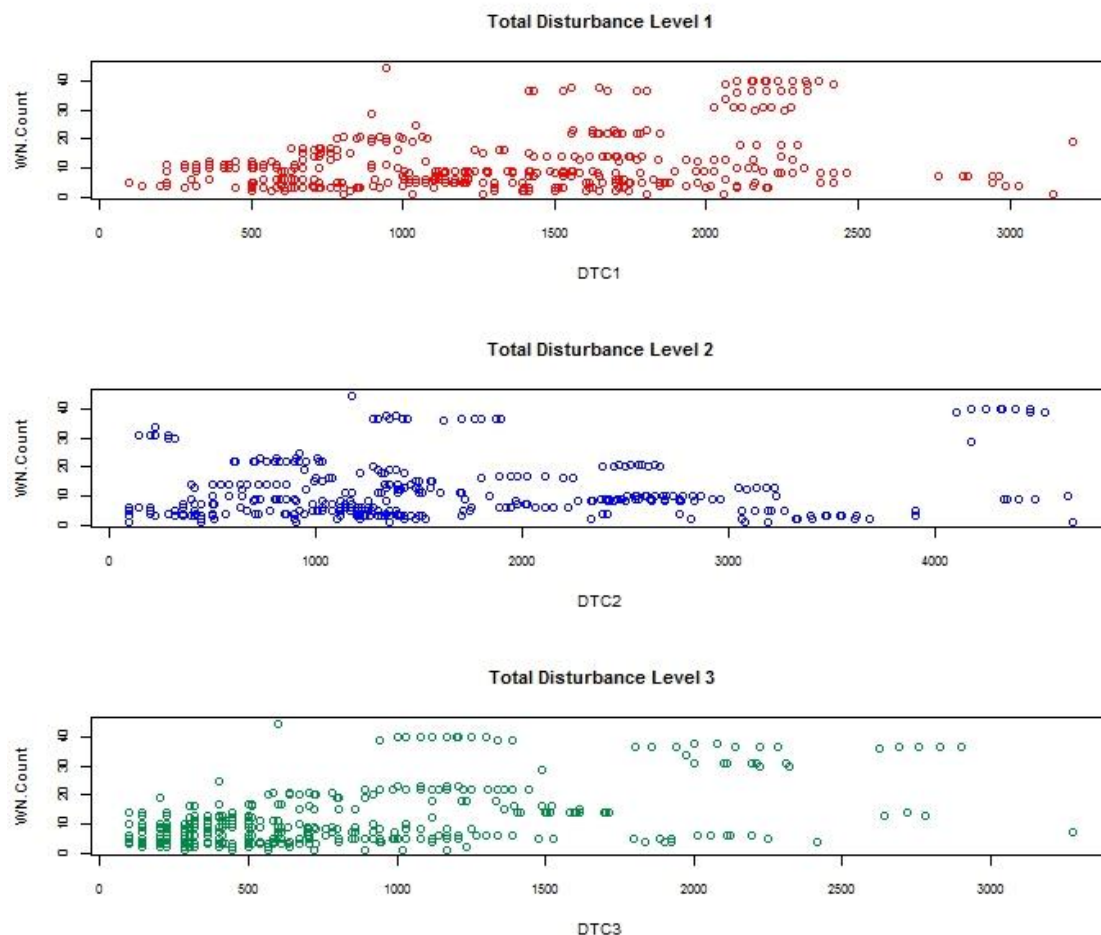


Figure 5.31: Teal distribution associated with distance (m) to each total disturbance category (DTC1, DTC2 and DTC3).

Upon further investigation, the majority of high Wigeon counts during construction were associated with shallow water and distances of up to 200m from the shoreline. With the exception of one aggregation, the high counts, (aggregations of up to 40 individuals) were found to be on the Central Section during September 2010 and August 2011 (Figure 5.32). Despite these high counts being recorded for the Central Section, the Hurdle model found overall numbers of Wigeon to be positively

associated with the Main Section. This is supported by results from the previous chapter which found that numbers of Wigeon across the site and within the Main Section significantly increased in years during construction compared to those pre-construction.

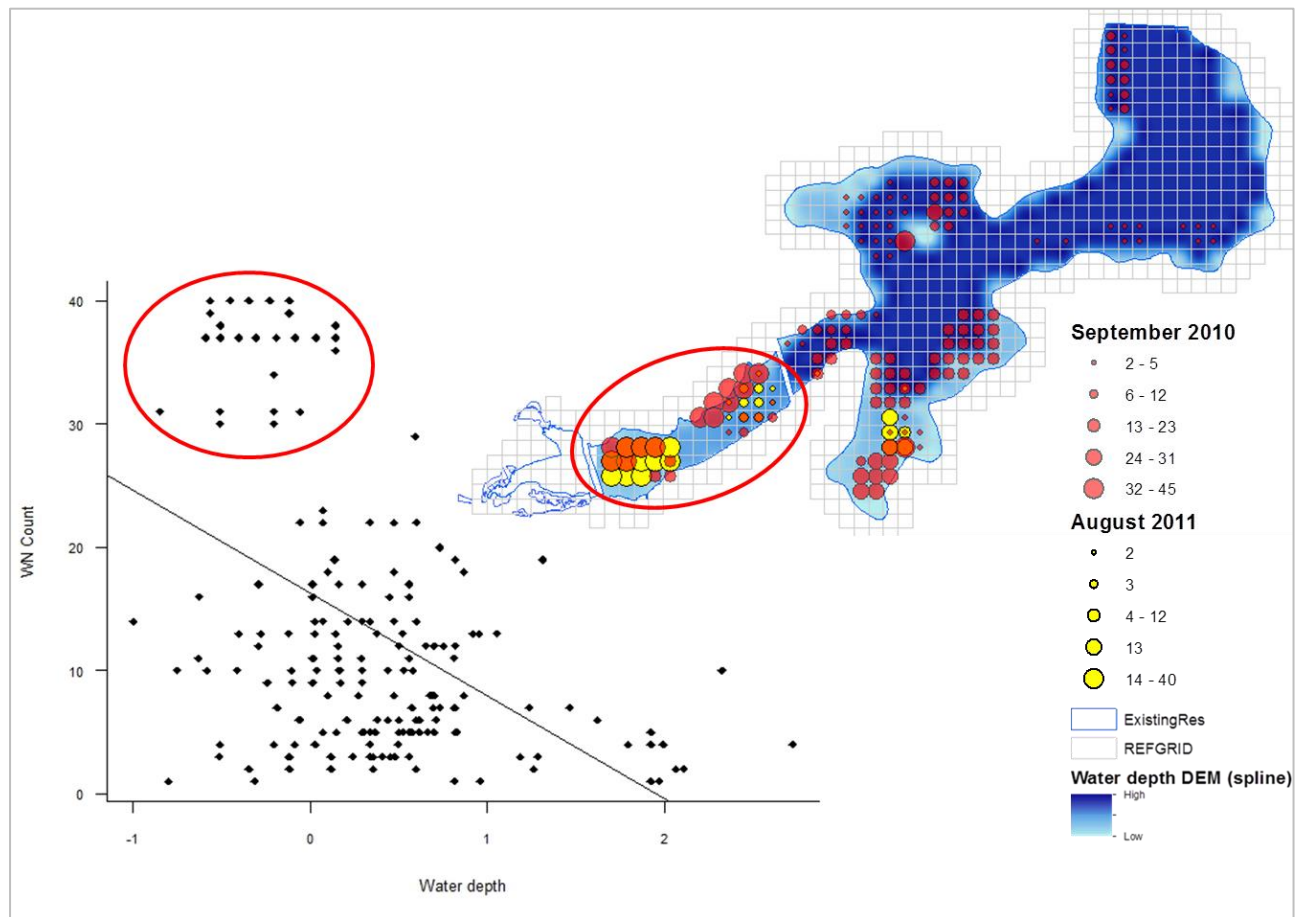


Figure 5.32: The relationship between Wigeon and water depth (m) at Abberton Reservoir shown on the plot with a regression line (standard linear model $R^2 = 0.1966$, $p < 0.001$). Counts above 30 were all recorded for September 2010 (red symbol) and August 2011 (yellow symbol).

5.4.2.5 Coot

5.4.2.5.1 Construction and waterfowl distribution mapping

Abberton Reservoir is the most important site in the UK for Coot with winter counts exceeding that of any other site (Appendix 4.4). Chapter 4 showed that significant clusters were present within all three sections of the reservoir and that compared with years pre-construction, numbers were significantly higher for the Main Section during construction (months April – September).

Further spatial analysis (previously counts for April – September were combined) shows that until July, Coot aggregations for years 2010 – 2013 (Figure 5.33) were comparatively low. Numbers increased through July and August peaking in September when Coot formed dense aggregations, particularly within the Main Section (Figure 5.34). Of the construction years, and within the two sections analysed here, Coot numbers were highest in years 2010 and 2011 with counts totalling around 15,000 in each year.

Like many of the SPA waterfowl of Abberton Reservoir, Coot showed a preference for the Central section and within the Main Section, the island, Wigborough and Hide Bay. That said, during 2012 and 2013 aggregations were seen throughout the Main Section although numbers were lower compared with the bays. Spatial mapping (Figures 5.33 and 5.34) shows that Coot were present within these preferred areas despite the occurrence of nearby construction activity suggesting they were not particularly sensitive to the disturbance, or that it did not result in Coot moving away from these locations.

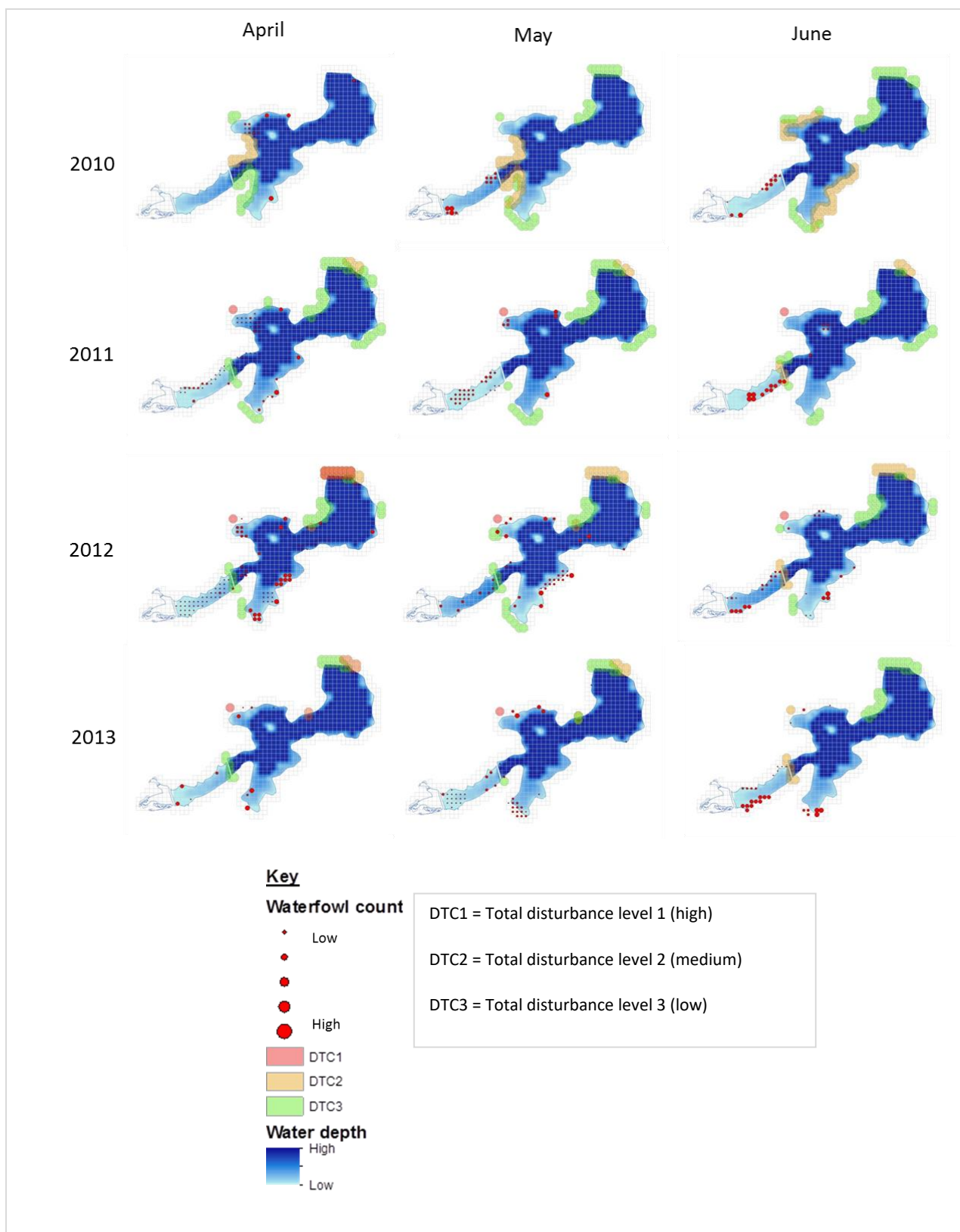


Figure 5.33: Coot distribution and extent of construction disturbance for months April, May and June 2010, 2011, 2012 and 2013. Counts vary each month and are represented for visual purposes on a natural breaks (Jenks) classification scale set to 5 classes and defined as low – high counts.

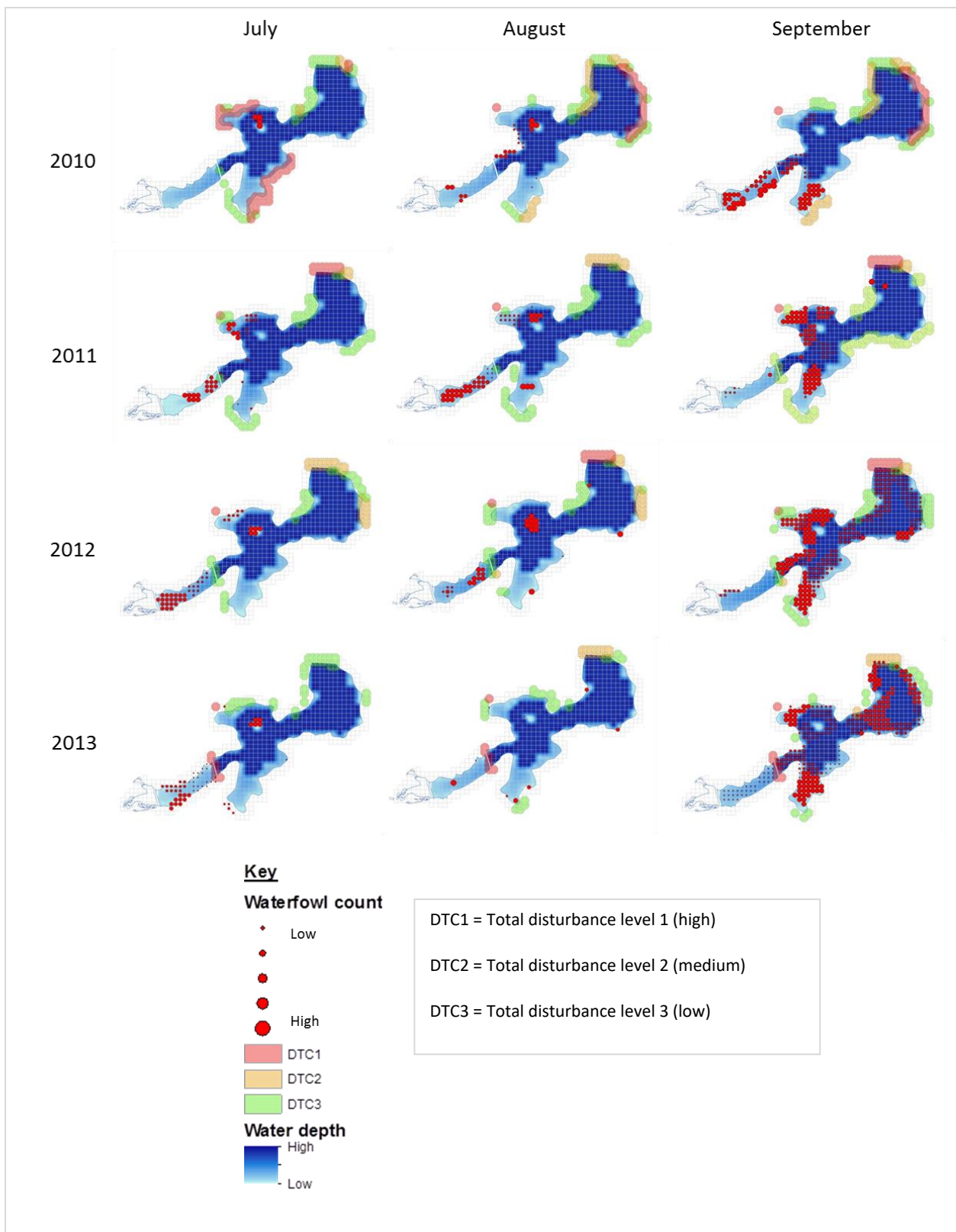


Figure 5.34: Coot distribution and extent of construction disturbance for months July, August and September 2010, 2011, 2012 and 2013. Counts vary each month and are represented for visual purposes on a natural breaks (Jenks) classification scale set to 5 classes and defined as low – high counts.

5.4.2.5.2 Statistical analysis

Results of Hurdle model analysis for Coot are shown in Table 5.17. Compared with the dabbling species, the MAM (for total, machine and people) are more complex with each containing many covariates. This could be a result of spatial autocorrelation, a missing covariate or suggests that Coots are less environmentally constrained than the dabbling species.

Environmental conditions accounting for numbers of Coot are year ($X^2 = 63.571$, $df = 22$, $p < 0.001$); section ($X^2 = 107.31$, $df = 24$, $p < 0.001$); water depth ($X^2 = 60.102$, $df = 24$, $p < 0.001$); temperature ($X^2 = 159.49$, $df = 24$, $p < 0.001$); wind speed ($X^2 = 67.845$, $df = 24$, $p < 0.001$); total rainfall ($X^2 = 87.634$, $df = 22$, $p < 0.001$) and the interaction between wind speed and total rainfall ($X^2 = 49.992$, $df = 24$, $p < 0.001$). Of those, the Main Section, increasing temperature, wind speed and rainfall were all shown to have a positive effect. The effect of increasing rainfall on Coot reduces as wind speed increases and numbers were also found to decrease with increasing water depth; a relationship seen pre-construction (Part A) and for other species in this study period.

Of the construction variables, only categories within the machine and people disturbance band were significant predictors on numbers of Coot. Although non-significant within the Hurdle model, for consistency with other species, numbers of Coot within each Refgrid in relation to distance to total construction activity are shown in Figure 5.35. All three categories of machine disturbance had a significant effect with increased distance to categories 1 ($X^2 = 13.148$, $df = 26$, $p < 0.001$), and 3 ($X^2 = 19.844$, $df = 26$, $p < 0.001$), associated with an increase in Coot. Distance to DTC2 was associated with a decrease in Coot numbers which may reflect a true category difference or it could be a false positive acting as a proxy for another spatial condition.

For the zero hurdle component; modelling the chance of a count or zero outcome, year ($X^2 = 167.51$, $df = 22$, $p < 0.001$); section ($X^2 = 298.91$, $df = 24$, $p < 0.001$); water depth ($X^2 = 127.96$, $df = 23$, $p < 0.001$); % macrophyte ($X^2 = 238.66$, $df = 23$, $p < 0.001$); temperature ($X^2 = 445.15$, $df = 24$, $p < 0.001$);

wind speed ($X^2 = 125.93$, $df = 24$, $p < 0.001$); rainfall ($X^2 = 198.36$, $df = 24$, $p < 0.001$) and the interaction between water depth and % macrophyte ($X^2 = 107.27$, $df = 24$, $p < 0.001$), all exerted a significant influence on the outcome. All of the significant construction variables, increasing distance to total disturbance 1, all three categories within people disturbance and DMC1 and DMC3 were associated with an increased chance of a zero outcome; largely supporting findings from the count component.

Table 5.17: Summary table of Hurdle model results for Coot in years during construction. Only variables with a confidence level of 95% (<0.05) are shown.

Variable	Z value	Significance (p-value)	Relationship
Count model (truncated negative binomial with log link)			
<i>Total construction disturbance</i>			
2011	-3.443	<0.001	-
2012	-6.743	<0.001	-
2013	-4.639	<0.001	-
Main Section	5.461	<0.001	+
Water depth	-3.884	<0.001	-
Temperature	6.616	<0.001	+
Wind speed	7.144	<0.001	+
Total rainfall	4.807	<0.001	+
Wind speed*total rainfall	-7.043	<0.001	-
<i>Machine construction disturbance</i>			
Construction (DMC1)	2.399	<0.05	+
Construction (DMC2)	-7.670	<0.001	-
Construction (DMC3)	4.115	<0.001	+
<i>People construction disturbance</i>			
Construction (DPC1)	-2.185	<0.05	-
Construction (DPC3)	-3.536	<0.001	-
Zero hurdle model (binomial with logit link)			
2012	9.961	<0.001	+
2013	7.995	<0.001	+
Main Section	-17.835	<0.001	-
Water depth	9.873	<0.001	+
% macrophyte	14.728	<0.001	+
Temperature	-20.435	<0.001	-
Wind speed	-11.099	<0.001	-
Total rainfall	-13.427	<0.001	-
Construction (DTC1)	-16.027	<0.001	-
Water depth*% macrophyte	-10.117	<0.001	-
<i>Machine construction disturbance</i>			

Construction (DMC1)	-9.347	<0.001	-
Construction (DMC3)	-2.627	<0.01	-
<i>People construction disturbance</i>			
Construction (DPC1)	-10.730	<0.001	-
Construction (DPC2)	-4.793	<0.001	-
Construction (DPC3)	-4.427	<0.001	-

N.B. Where * indicates an interaction

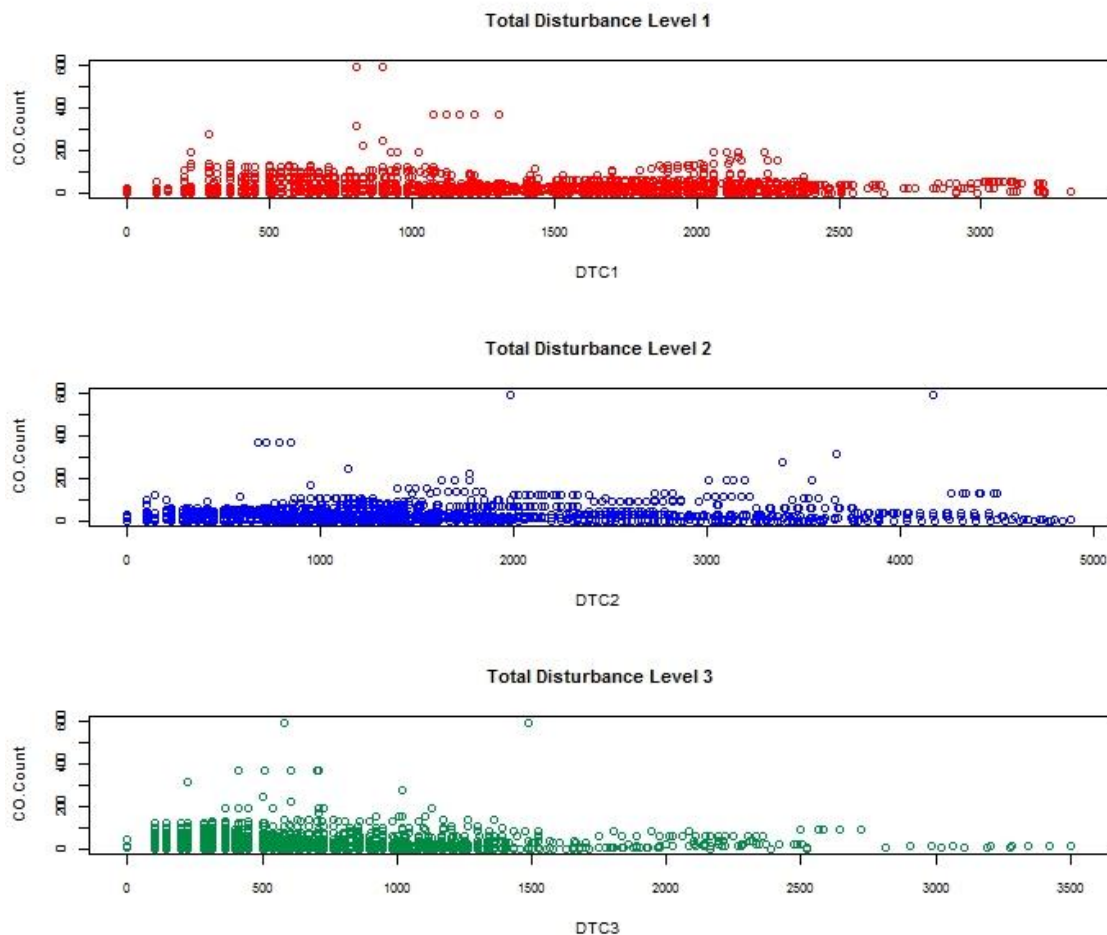


Figure 5.35: Coot distribution associated with distance (m) to each total disturbance category (DTC1, DTC2 and DTC3). For consistency with other species total disturbance is shown.

In years pre-construction, Coots were found to be associated with higher macrophyte cover. During construction the relationship was not as strong although increasing cover was still associated with a higher chance of a positive count. The association with temperature and wind speed was the same however a shift in distribution from the Central to the Main Section was observed. The relationship of Coot with water depth, shown in Figure 5.36 was essentially the same as pre-construction with numbers and the chance of a count outcome decreasing with increasing depth. It should be

acknowledged however, that although statistically significant, water depth alone only explains 8% of the observed variation in numbers of Coot.

Compared to pre-construction analysis, Coot during construction were located at shallower depths although this may be a result of the lowering of water levels during construction. It should also be noted that for the Hurdle model, 12 outliers were removed but are included in Figure 5.36. Ten of the removed counts were from the Main Section, four counted in deep water (>4m depth) and five formed one large raft near Hide Bay in August 2012.

Results from linear regression did not find any relationship between Coot and distance to shoreline with counts fairly evenly distributed within 400m of the shoreline. This is the same distance reported analysis pre-construction.

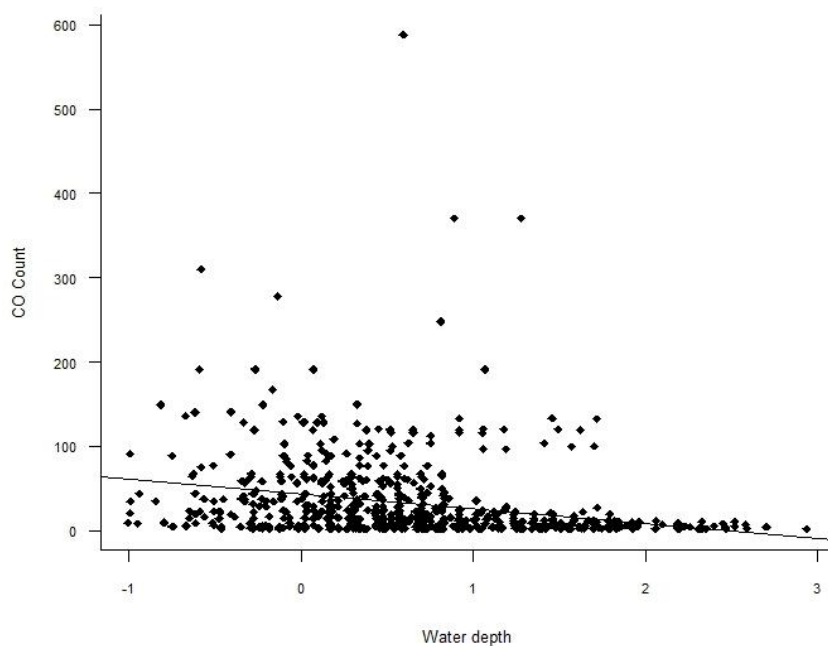


Figure 5.36: The relationship between Coot and water depth (m) at Abberton Reservoir (shown with a regression line (standard linear model $R^2 = 0.07672$, $p < 0.001$). Note that all counts were included for this plot but the higher counts were removed as outliers from the Hurdle model.

5.4.2.6 Tufted Duck

Counts of Tufted Duck at Abberton Reservoir are highest during August and September although they can also peak in April (for months April – September). Analysis pre-construction found strong positive associations with deeper water, aquatic vegetation and also with increasing wind speed and temperature which promoted a clustered distribution. Numbers during the spring/summer months did not significantly differ between the two study periods however they were found to significantly decrease during construction across the site and in the Central Section for the winter months (Chapter 4).

5.4.2.6.1 Construction and waterfowl distribution mapping

Tufted Duck distribution and the location and magnitude of construction activity have been mapped and are shown in Figure 5.37 for the months of April – June and for July – September in Figure 5.38. Aggregations were prominent for April, August and September although, as reported for other species, there was a lack of Tufted Duck for August 2013. They did not have any particular distribution pattern although were consistently present near Hide and Wigborough Bay and for the majority of months, the Central Section. This section was densely occupied during August 2012 with high numbers of Tufted Duck close to low level disturbance caused by causeway construction works. Aggregations in this section were located further away from high impact disturbance; a pattern not seen for the Main Section suggesting impacts of disturbance has a greater impact on smaller water bodies.

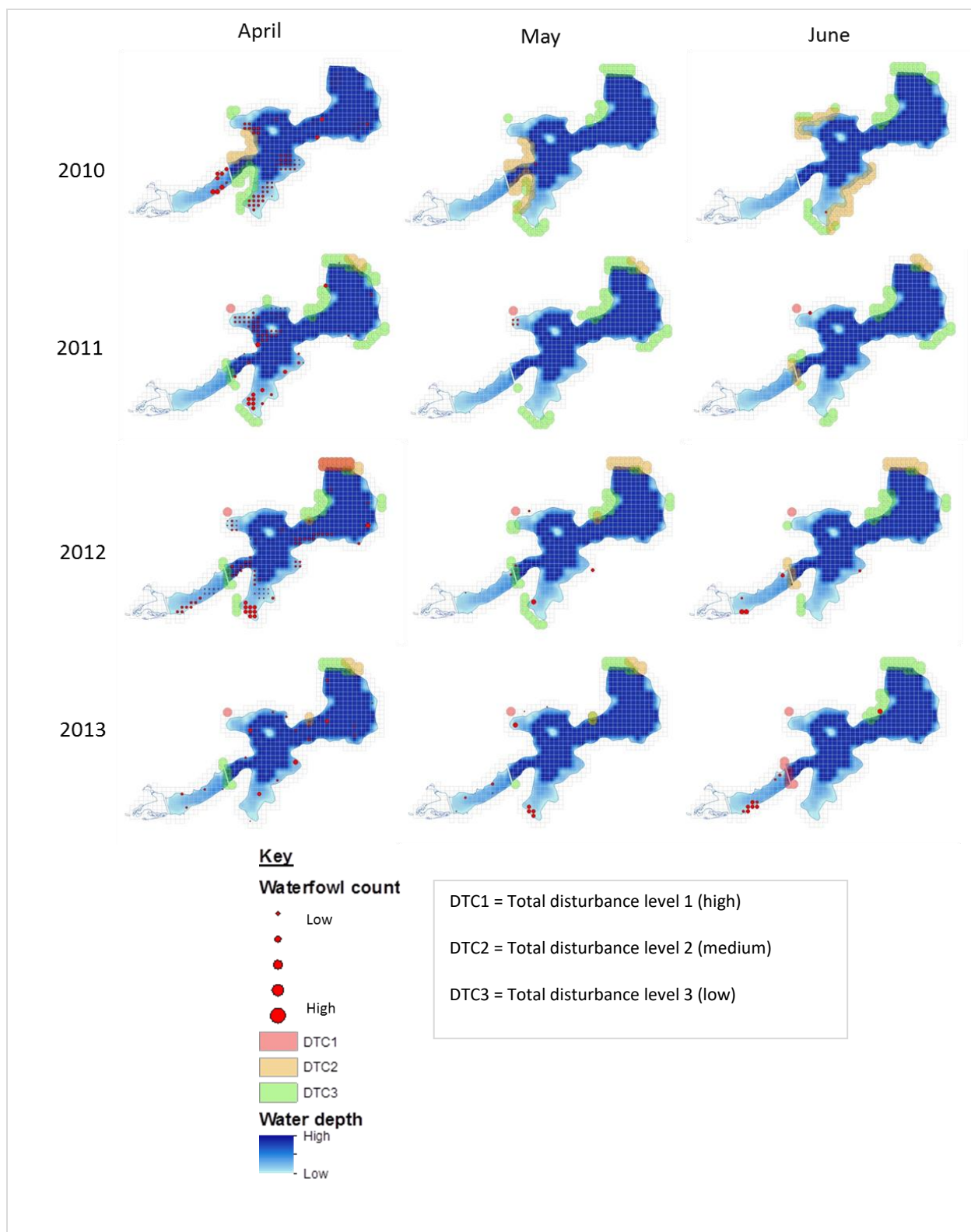


Figure 5.37: Tufted Duck distribution and extent of construction disturbance for months April, May and June 2010, 2011, 2012 and 2013. Counts vary each month and are represented for visual purposes on a natural breaks (Jenks) classification scale set to 5 classes and defined as low – high counts.

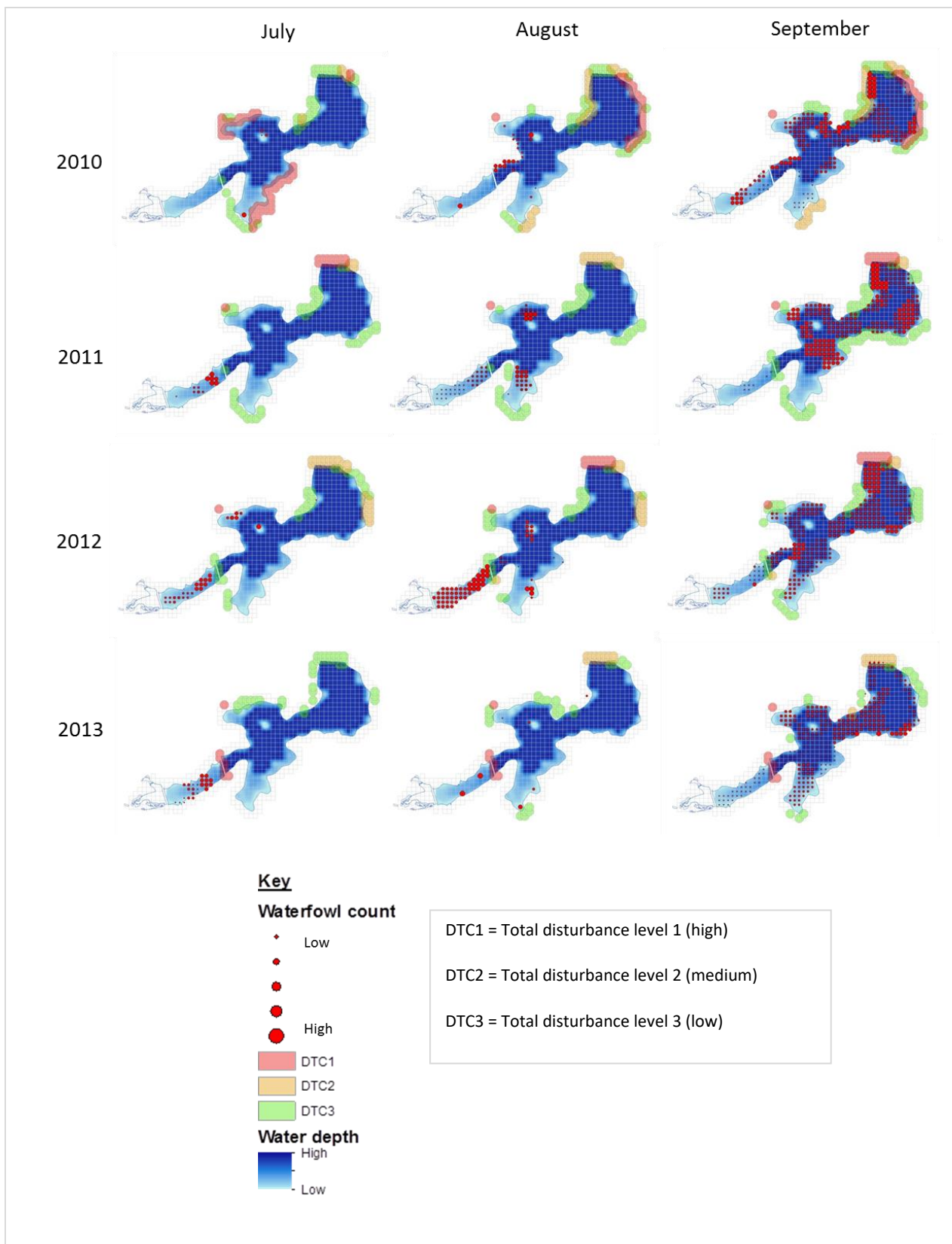


Figure 5.38: Tufted Duck distribution and extent of construction disturbance for months July, August and September 2010, 2011, 2012 and 2013. Counts vary each month and are represented for visual purposes on a natural breaks (Jenks) classification scale set to 5 classes and defined as low – high counts.

5.4.2.6.2 Statistical analysis

A summary of Hurdle model analysis for this species is shown in Table 5.18. Results found year ($X^2 = 256$, $df = 24$, $p < 0.001$) to be important with 2011, 2012 and 2013 all shown as negative count predictors. The zero model found a positive relationship for years 2012 and 2013; when overall numbers of Tufted Duck were lowest. Yearly counts were however comparatively similar with totals each year between 4300 and 4460.

Analysis found reservoir section ($X^2 = 31.503$, $df = 26$, $p < 0.001$); temperature ($X^2 = 506.53$, $df = 26$, $p < 0.001$); wind speed ($X^2 = 160.99$, $df = 26$, $p < 0.001$); total construction category 1 ($X^2 = 55.858$, $df = 26$, $p < 0.001$); category 3 ($X^2 = 18.119$, $df = 26$, $p < 0.001$) and the interaction between water depth and % macrophyte ($X^2 = 8.3859$, $df = 26$, $p < 0.001$) to be significant predictor variables. The strong positive relationship of increasing temperatures and wind speed was also found for years pre-construction suggesting at Abberton Reservoir that these are particularly influential variables for Tufted Duck. Increasing water depth was not found to be significant in the prediction of Tufted Duck numbers, but was for a count outcome ($X^2 = 299.84$, $df = 25$, $p < 0.001$), indicating that during construction, Tufted Duck were more likely to be found in deeper water although not necessarily in large aggregations. Consistent with findings from previous analysis, the Main section was a significant positive predictor for numbers and for the occurrence of a positive count.

Spatial analysis, together with results of the Hurdle model, provides evidence to suggest higher magnitudes of construction activity were more disturbing to Tufted Duck than lower level activities. Higher numbers of this species were associated with increasing distance from all three level 1 categories (total $X^2 = 63.571$, $df = 22$, $p < 0.001$, machine $X^2 = 63.571$, $df = 22$, $p < 0.001$ and people $X^2 = 63.571$, $df = 22$, $p < 0.001$), and aggregations were situated closer to the lowest levels of total ($X^2 = 18.119$, $df = 26$, $p < 0.001$) and machine based construction activities ($X^2 = 19.175$, $df = 26$, $p < 0.001$). Numbers of Tufted Duck in relation to distance to total construction are shown in Figure 5.39.

Table 5.18: Summary table of Hurdle model results for Tufted Duck in years during construction. Only variables with a confidence level of 95% (<0.05) are shown.

Variable	Z value	Significance (p-value)	Relationship
Count model (truncated negative binomial with log link)			
<i>Total construction disturbance</i>			
2011	-11.784	<0.001	-
2012	-15.709	<0.001	-
2013	-11.201	<0.001	-
Main Section	5.762	<0.001	+
Temperature	23.207	<0.001	+
Wind speed	12.885	<0.001	+
Construction (DTC1)	6.929	<0.001	+
Construction (DTC3)	-3.995	<0.001	-
% macrophyte*water depth	2.886	<0.001	+
<i>Machine construction disturbance</i>			
Construction (DMC1)	8.231	<0.001	+
Construction (DMC3)	-3.973	<0.001	-
<i>People construction disturbance</i>			
Construction (DPC1)	1.997	<0.05	+
Zero hurdle model (binomial with logit link)			
2012	10.879	<0.001	+
2013	9.297	<0.001	+
Main section	-14.228	<0.001	-
% macrophyte	15.437	<0.001	+
Water depth	15.372	<0.001	+
Temperature	-23.950	<0.001	-
Wind speed	-10.542	<0.001	-
Total rainfall	-17.413	<0.001	-
Construction (DTC1)	-17.648	<0.001	-
Construction (DTC3)	-3.737	<0.001	-
% macrophyte*Water depth	-10.780	<0.001	-
<i>Machine construction disturbance</i>			
Construction (DMC1)	-10.137	<0.001	-
Construction (DMC2)	-7.277	<0.001	-
Construction (DMC3)	-2.467	<0.01	-
<i>People construction disturbance</i>			
Construction (DPC1)	-10.554	<0.001	-
Construction (DPC2)	-10.945	<0.001	-
Construction (DPC3)	-6.462	<0.001	-

N.B. Where * indicates an interaction

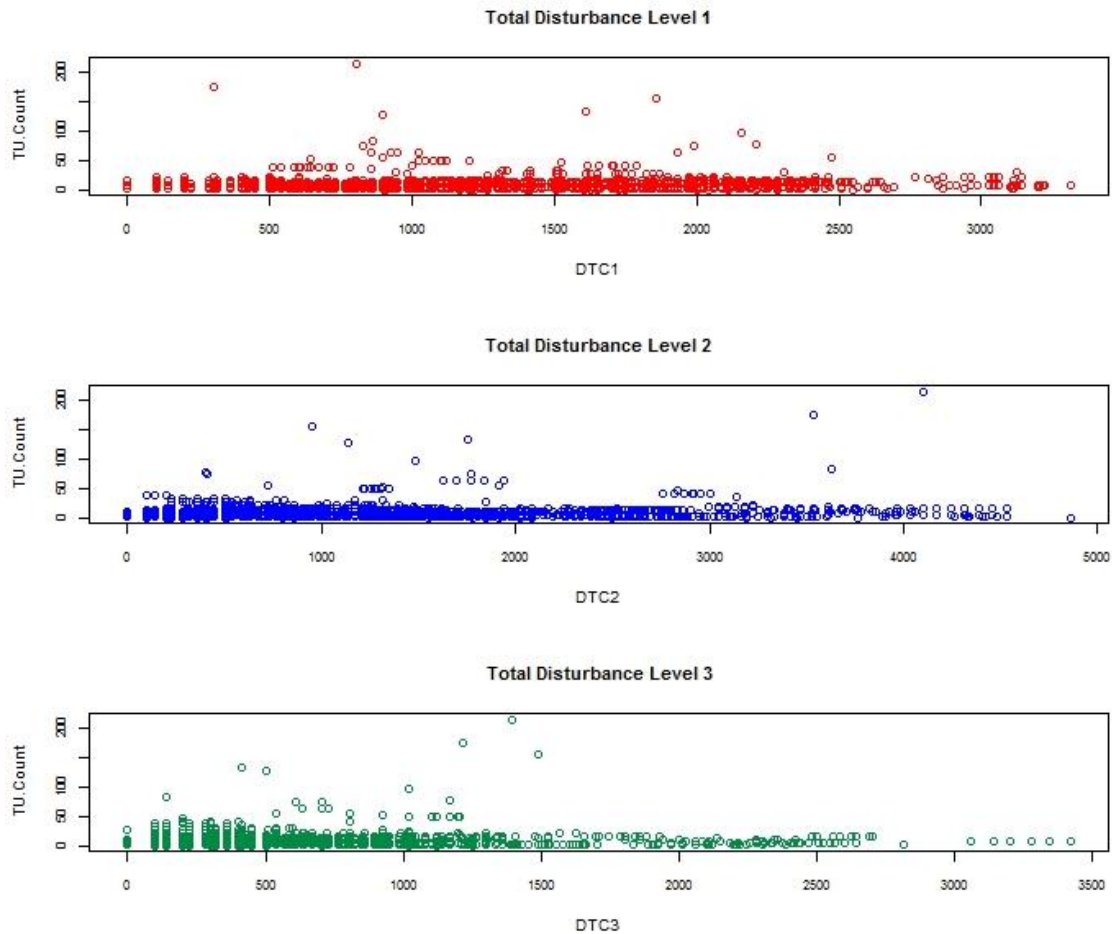


Figure 5.39: Tufted Duck distribution associated with distance (m) to each total disturbance category (DTC1, DTC2 and DTC3).

5.2.2.7 Pochard

Numbers of Pochard at Abberton Reservoir start increasing in August and peak during September (for months April – September). Comparisons of count data during construction with years pre-construction found no significant differences although similarities with Tufted Duck were observed. Between years 2010 and 2013, Pochard formed dense clusters within the Main Section, especially within Hide Bay and the northern parts of the reservoir during 2011; a pattern that was also seen during 2008.

5.4.2.7.1 Construction and waterfowl distribution mapping

The distribution of Pochard throughout the active construction period (April – September) are mapped and shown for the months of April – June in Figure 5.40 and July – August in Figure 5.41.

Plots also show the location and magnitude of construction activity and initially suggest that Pochard were not displaced from areas of the reservoir subject to disturbance. Aggregations are seen by the B1026 causeway during times of low, medium and high construction events and also by the offtake pumping station and the main dam; areas of constant activity. The presence of this species by the causeway in consecutive months may be suggestive of habituation although it is difficult to determine if individuals present in one month are the same the following month; particularly during the migratory period.

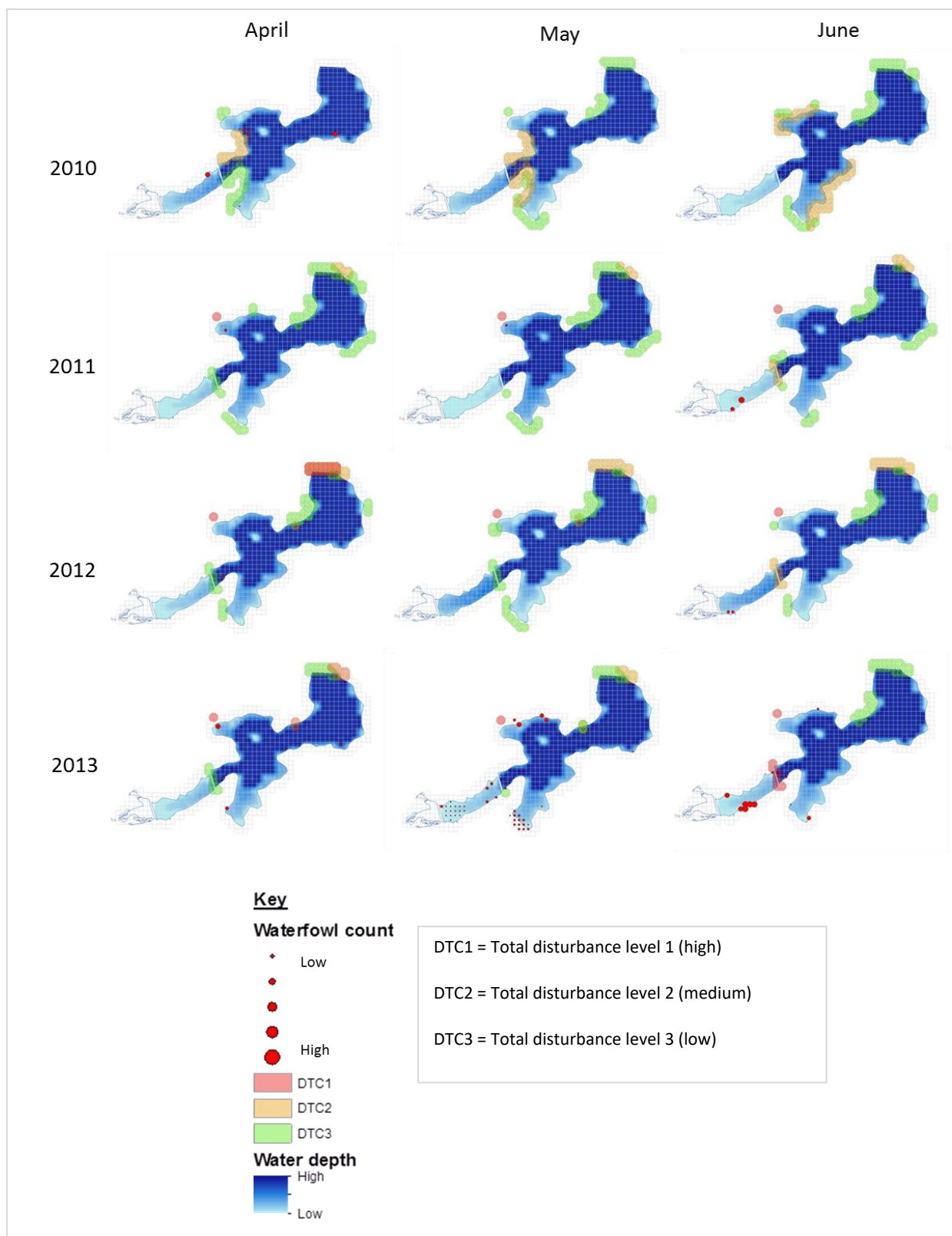


Figure 5.40: Pochard distribution and extent of construction disturbance for months April, May and June 2010, 2011, 2012 and 2013. Counts vary each month and are represented for visual purposes on a natural breaks (Jenks) classification scale set to 5 classes and defined as low – high counts.

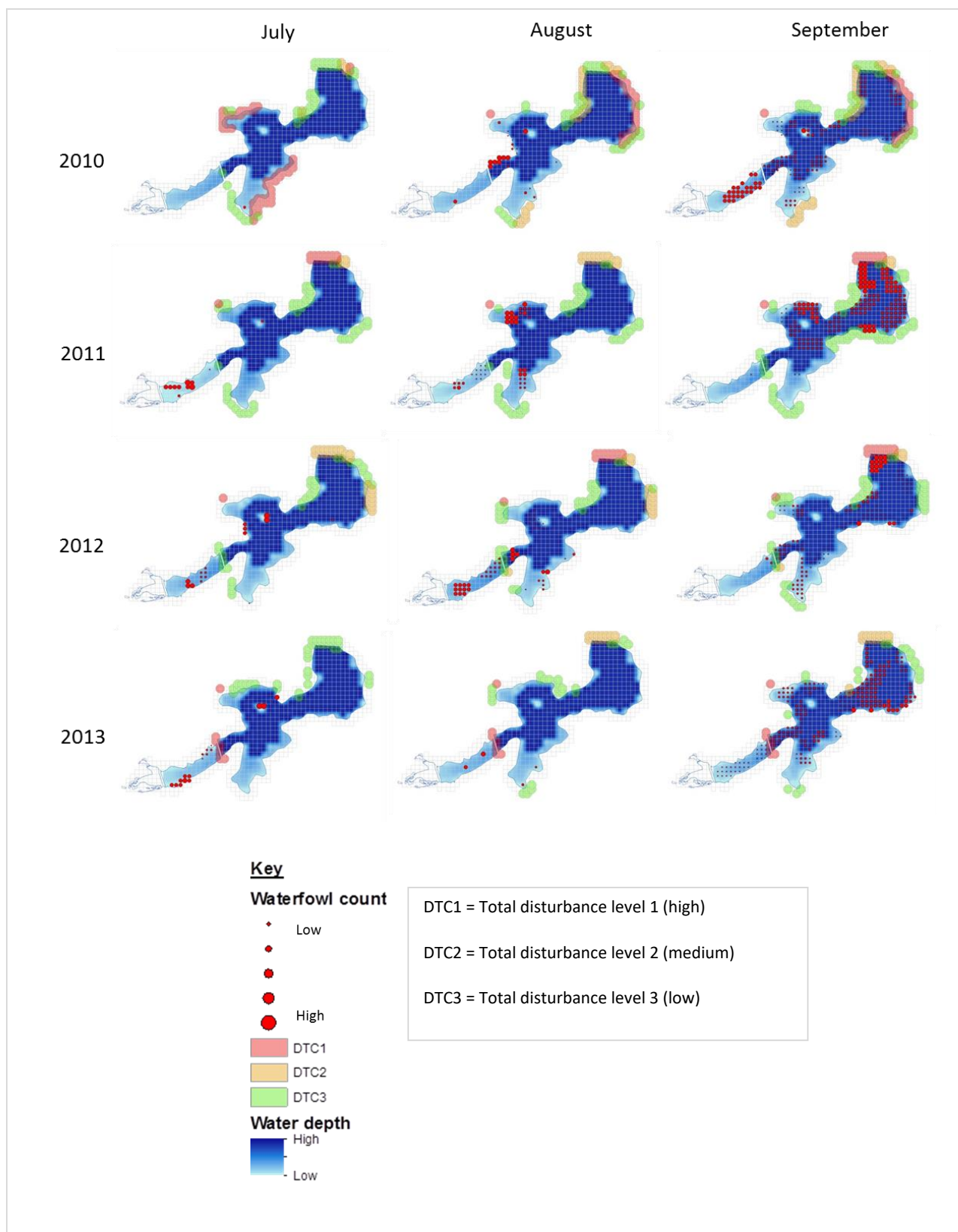


Figure 5.41: Pochard distribution and extent of construction disturbance for months July, August and September 2010, 2011, 2012 and 2013. Counts vary each month and are represented for visual purposes on a natural breaks (Jenks) classification scale set to 5 classes and defined as low – high counts.

5.4.2.7.2 Statistical analysis

A summary of results for Hurdle model analysis for Pochard is shown in Table 5.19. Covariates found to have an influence on numbers of Pochard include year ($\chi^2 = 29.634$, $df = 23$, $p < 0.001$); % macrophyte ($\chi^2 = 24.423$, $df = 25$, $p < 0.001$); temperature ($\chi^2 = 128.98$, $df = 25$, $p < 0.001$); distance to category 2 ($\chi^2 = 81.73$, $df = 25$, $p < 0.001$); category 3 ($\chi^2 = 44.469$, $df = 25$, $p < 0.001$) and the interaction between wind speed and total rainfall ($\chi^2 = 5.7458$, $df = 25$, $p < 0.05$). The relationship between numbers of Pochard and 2012, 2013 and DTC2 is negative while the effect of increasing aquatic vegetation, temperature, DTC3 and the interaction is positive. The zero model also shows a positive relationship with macrophyte cover ($\chi^2 = 140.08$, $df = 24$, $p < 0.001$) demonstrating that this species during construction, had a strong affinity with aquatic vegetation; increasing percentage cover was associated with both the prediction of higher counts and occurrence of Pochard. Pre-construction, higher percentages of vegetation predicted the occurrence of Pochard but lower total counts. This observed difference between the two study periods may represent a behavioural or locational shift; possibly attributed to disturbance or reflective of habitat modification.

Pochard are classified as a diving duck species and are typically associated with deeper water. For years during construction the Hurdle model predicted a greater chance of a count outcome (zero component) with increasing depths ($\chi^2 = 113.4$, $df = 24$, $p < 0.001$). For numbers of Pochard (count component), this association was not found with aggregations in all eight study years distributed between depths of 0 and 4m.

Table 5.19: Summary table of Hurdle model results for Pochard in years during construction. Only variables with a confidence level of 95% (< 0.05) are shown.

Variable	Z value	Significance (p-value)	Relationship
Count model (truncated negative binomial with log link)			
<i>Total construction disturbance</i>			
2012	-2.907	<0.001	-
2013	-2.505	<0.01	-
% macrophyte	3.099	<0.001	+
Temperature	11.118	<0.001	+

Construction (DTC2)	-7.945	<0.001	-
Construction (DTC3)	8.258	<0.001	+
Wind speed*total rainfall	2.744	<0.01	+
<i>Machine construction disturbance</i>			
Construction (DMC1)	3.356	<0.001	+
Construction (DMC3)	5.132	<0.001	+
<i>People construction disturbance</i>			
Construction (DPC1)	7.217	<0.001	+
Construction (DPC2)	1.982	<0.05	+
Construction (DPC3)	4.145	<0.001	+
Zero hurdle model (binomial with logit link)			
2012	4.146	<0.001	+
2013	6.555	<0.001	+
Main Section	-9.958	<0.001	-
% macrophyte	10.616	<0.001	+
Water depth	9.465	<0.001	+
Temperature	-13.620	<0.001	-
Wind speed	-8.496	<0.001	-
Total rainfall	-12.697	<0.001	-
Construction (DTC1)	-14.482	<0.001	-
Construction (DTC2)	-4.743	<0.001	-
% macrophyte*water depth	-6.846	<0.001	-
<i>Machine construction disturbance</i>			
Construction (DMC1)	-11.302	<0.001	-
Construction (DMC2)	-13.944	<0.001	-
<i>People construction disturbance</i>			
Construction (DPC1)	-10.372	<0.001	-
Construction (DPC2)	-13.376	<0.001	-
Construction (DPC3)	-6.673	<0.001	-

N.B. Where * indicates an interaction

Results for the construction categories appear somewhat confusing with the count model predicting increased numbers of Pochard with increasing distance to all significant categories except DTC2, yet the zero model predicting a greater chance of a zero observation with increased distance. Plotting these relationships (shown in Figure 5.42 for total construction) does not highlight any obvious patterns although the spread of counts is greater for category 2, potentially explaining the Hurdle model results.

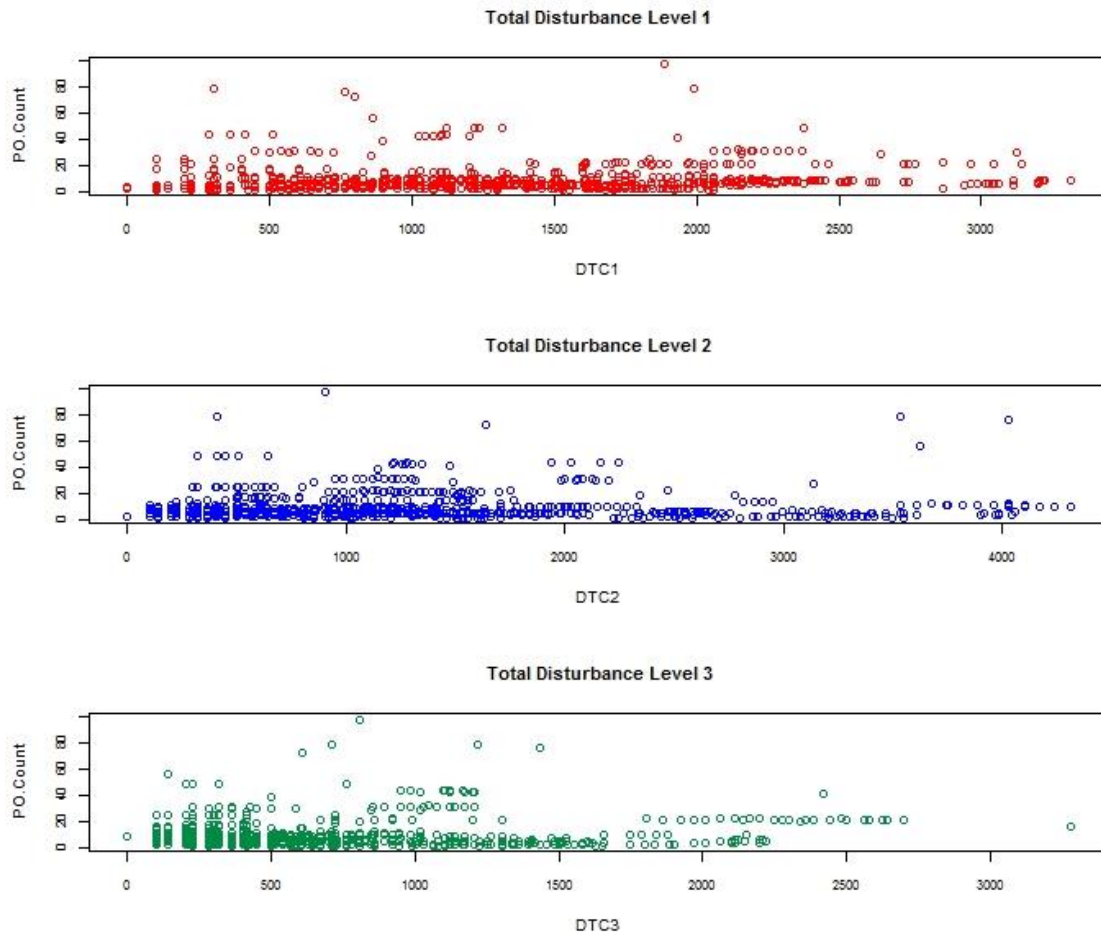


Figure 5.42: Pochard distribution associated with distance (m) to each total disturbance category (DTC1, DTC2 and DTC3).

The distances involved at Abberton Reservoir together with the phased construction programme and environmental conditions may account for some of the results reported. Throughout the construction period areas of the Main Reservoir shoreline were devoid of construction disturbance enabling waterfowl to redistribute to these areas or to occupy the central parts of the reservoir. This redistribution may have had subtle spatial impacts on this species which are demonstrated by the results. One noted change was with aquatic vegetation, which at Abberton Reservoir is typically at closer distances to the shoreline but not necessarily within close proximity to construction. This could account for the change in relationship with Pochard and distance to shoreline changing from positive pre-construction (Part A) to weakly negative during construction (Figure 5.43).

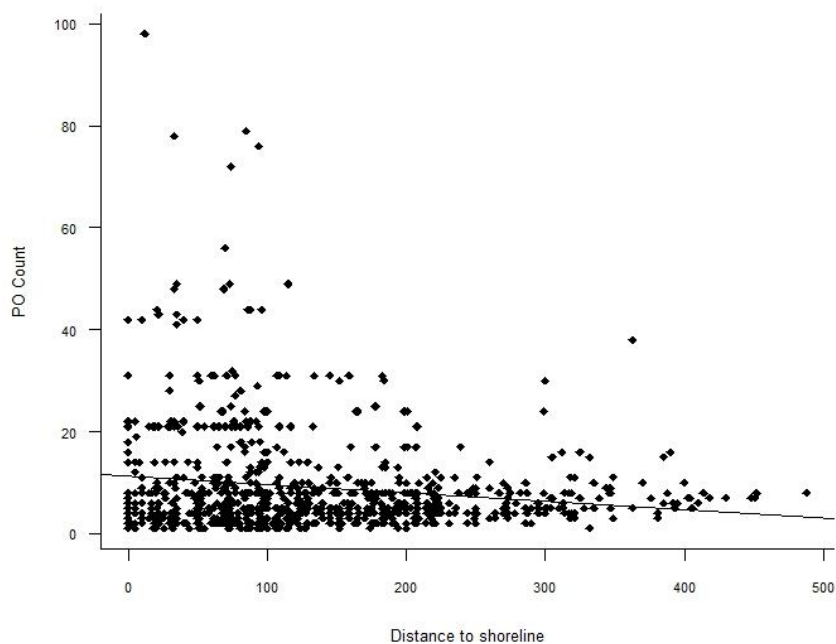


Figure 5.43: The relationship between Pochard and distance to shoreline (m) at Abberton Reservoir (shown with a regression line (standard linear model $R^2 = 0.02362$, $p < 0.001$)).

5.4.2.8 Mute Swan

5.4.2.8.1 Construction and waterfowl distribution mapping

As noted in the previous chapter, the spatial distribution of Mute Swan during construction differs from that observed in baseline years. Use of the Western Section reduced and a decline was noted for the Central Section. Large numbers of this species in years 2006 - 2009 aggregated along the Central section shoreline whereas during 2010 - 2013, they were largely confined to the Main Section. Although not significant in statistical analysis, the preference for the Main Section can be seen in Figures 5.44 and 5.45 which combine the distribution of Mute Swan with the locations of construction activity (2010 - 2013) for months April – June (Figure 5.44) and for July - September (Figure 5.45).

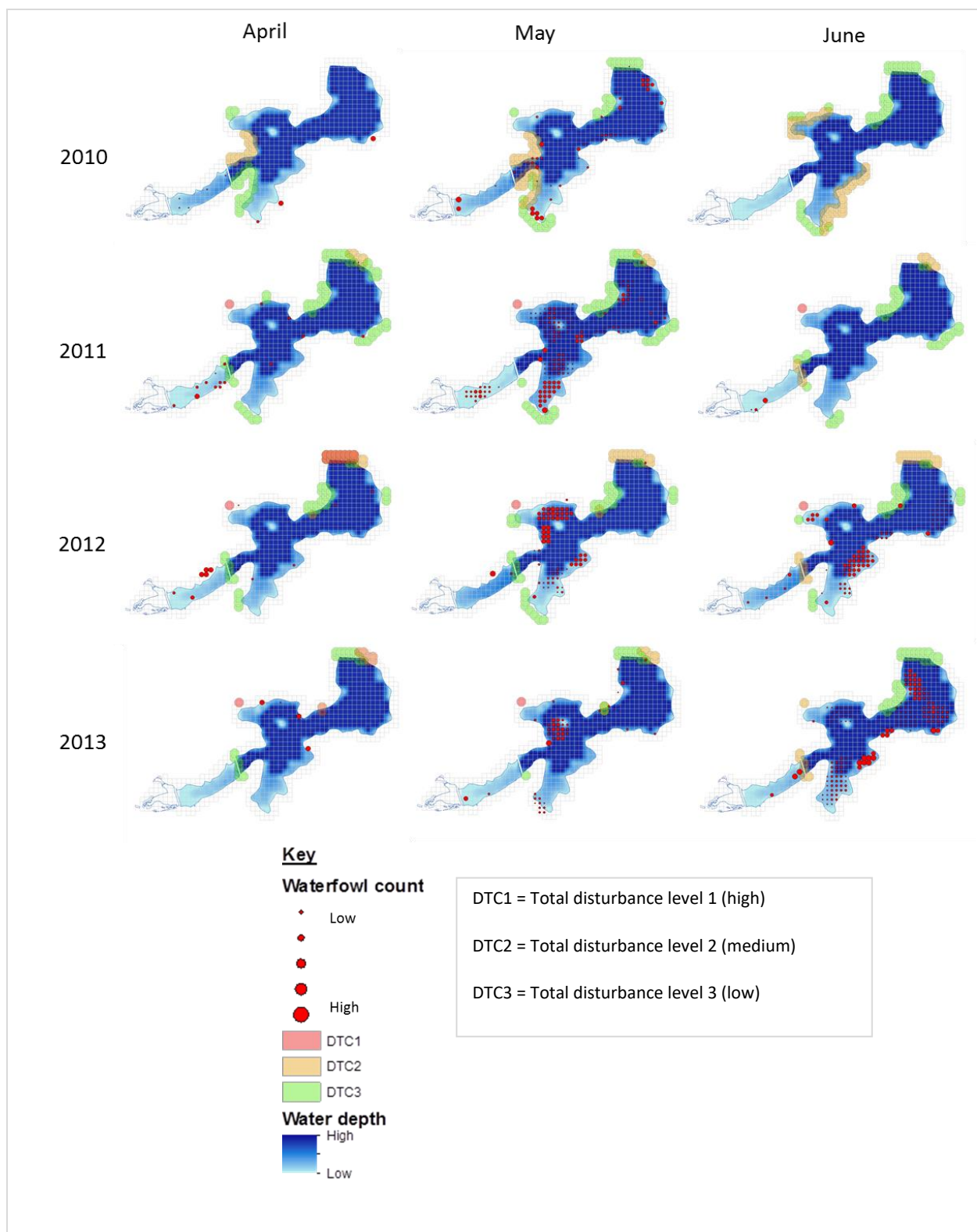


Figure 5.44: Mute Swan distribution and extent of construction disturbance for months April, May and June 2010, 2011, 2012 and 2013. Counts vary each month and are represented for visual purposes on a natural breaks (Jenks) classification scale set to 5 classes and defined as low – high counts.

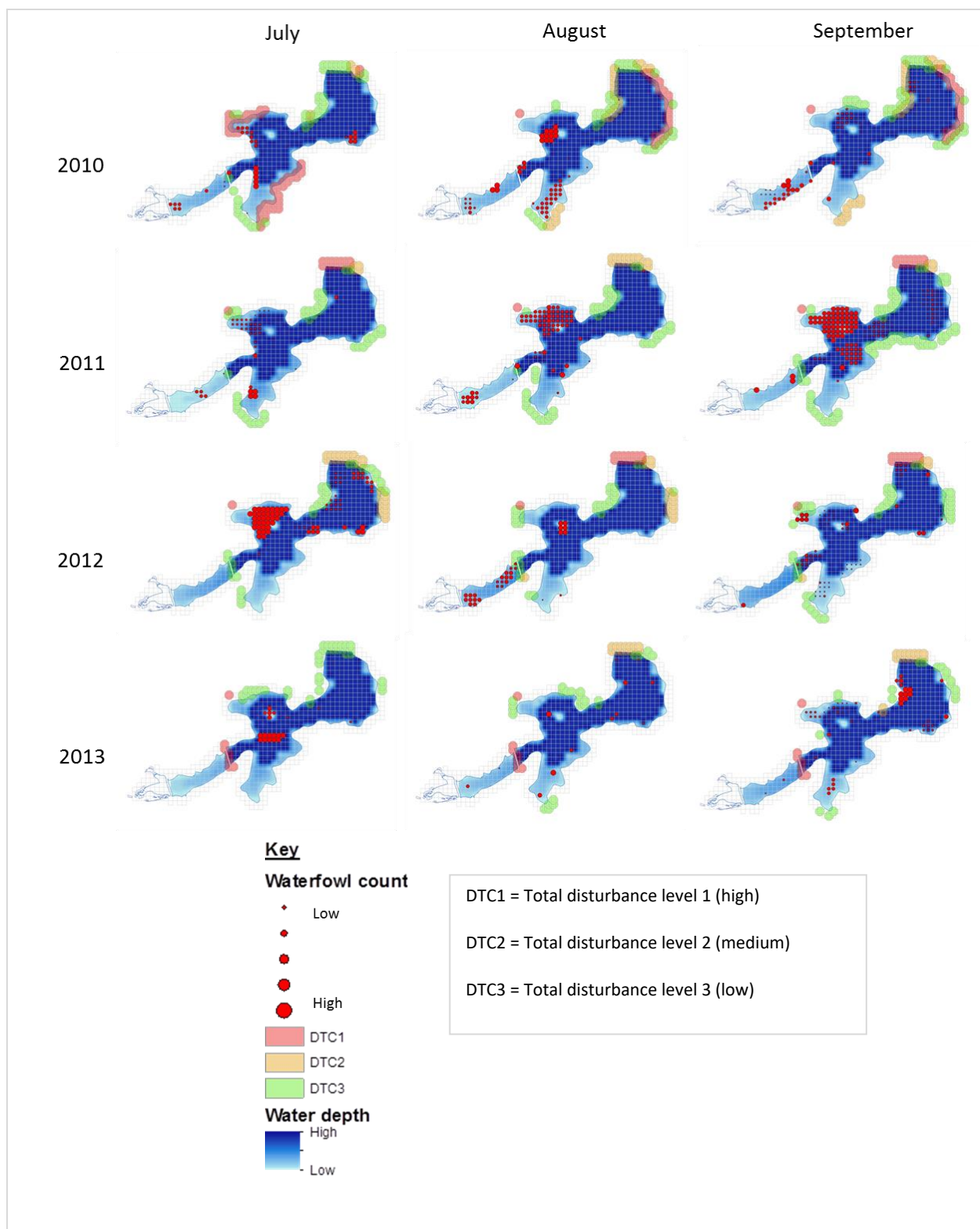


Figure 5.45: Mute Swan distribution and extent of construction disturbance for months July, August and September 2010, 2011, 2012 and 2013. Counts vary each month and are represented for visual purposes on a natural breaks (Jenks) classification scale set to 5 classes and defined as low – high counts.

Spatial mapping illustrates that during July, August and September when counts peaked, Hide Bay was of principal importance. Pre-construction analysis showed birds to be highly dispersed throughout the reservoir yet pronounced clustering is seen during construction. This may be due to increases in flock size as a result of habitat alterations or be reflective of a disturbance response.

5.4.2.8.2 Statistical analysis

Statistical analysis, a summary of which is provided in Table 5.20 found a negative relationship with numbers of Mute Swan to all of the high disturbance categories; DTC1 ($\chi^2 = 40.054$, $df = 24$, $p < 0.001$), DMC1 ($\chi^2 = 7.1158$, $df = 25$, $p < 0.01$) and DPC1 ($\chi^2 = 96.76$, $df = 26$, $p < 0.001$) and is supported by results from the zero component. The fact that occurrence and counts of Mute Swan decreased with increasing distance from shoreline disturbance suggests they were not overly perturbed by events or that this species did not differentiate between magnitudes of construction. However, irrespective of the relationship direction, Mute Swan maintained greater distances from high disturbance categories with counts of more than 10 birds at least 300m from construction. This was not observed for the lowest categories with high counts located within short distances from disturbance events. Figure 5.46 illustrates this relationship and shows the distance of Mute Swan to all three total disturbance categories.

Environmental variables found to influence counts were water depth ($\chi^2 = 36.683$, $df = 24$, $p < 0.001$); temperature ($\chi^2 = 42.384$, $df = 23$, $p < 0.001$); rainfall ($\chi^2 = 28.17$, $df = 24$, $p < 0.001$) and wind speed ($\chi^2 = 9.5143$, $df = 23$, $p < 0.01$). The association with water depth was negative i.e. higher counts occur at shallower depths and the relationship with wind, rain and temperature was positive; a finding also reported for years pre-construction (Part A). Similarly, the relationship with macrophytes and a count occurrence was found across all eight study years.

Table 5.20: Summary table of Hurdle model results for Mute Swan in years during construction. Only variables with a confidence level of 95% (<0.05) are shown.

Variable	Z value	Significance (p-value)	Relationship
Count model (truncated negative binomial with log link)			
<i>Total construction disturbance</i>			
2011	-5.421	<0.001	-
2012	-5.108	<0.001	-
Water depth	-5.881	<0.001	-
Temperature	5.273	<0.001	+
Total rainfall	5.289	<0.001	+
Wind speed	2.327	<0.05	+
Construction (DTC1)	-4.532	<0.001	-
Construction (DTC2)	5.115	<0.001	+
Temperature*wind speed	-2.950	<0.001	-
<i>Machine construction disturbance</i>			
Construction (DMC1)	-2.276	<0.05	-
Construction (DMC2)	-4.152	<0.001	-
Construction (DMC3)	5.350	<0.001	+
<i>People construction disturbance</i>			
Construction (DPC1)	-5.012	<0.001	-
Zero hurdle model (binomial with logit link)			
2011	8.716	<0.001	+
2012	6.423	<0.001	+
2013	-3.211	<0.001	-
% macrophyte	13.007	<0.001	+
Water depth	10.384	<0.001	+
Temperature	4.857	<0.001	+
Wind speed	5.291	<0.001	+
Total rainfall	-2.048	<0.05	-
Construction (DTC1)	-7.838	<0.001	-
Construction (DTC3)	7.056	<0.001	+
% macrophyte*water depth	-7.753	<0.001	-
Temperature*wind speed	-2.651	<0.01	-
<i>Machine construction disturbance</i>			
Construction (DMC1)	-5.051	<0.001	-
Construction (DMC2)	2.660	<0.01	+
Construction (DMC3)	7.490	<0.001	+
<i>People construction disturbance</i>			
Construction (DPC1)	-9.875	<0.001	-
Construction (DPC2)	5.268	<0.001	+
Construction (DPC3)	5.450	<0.001	+

N.B. Where * indicates an interaction

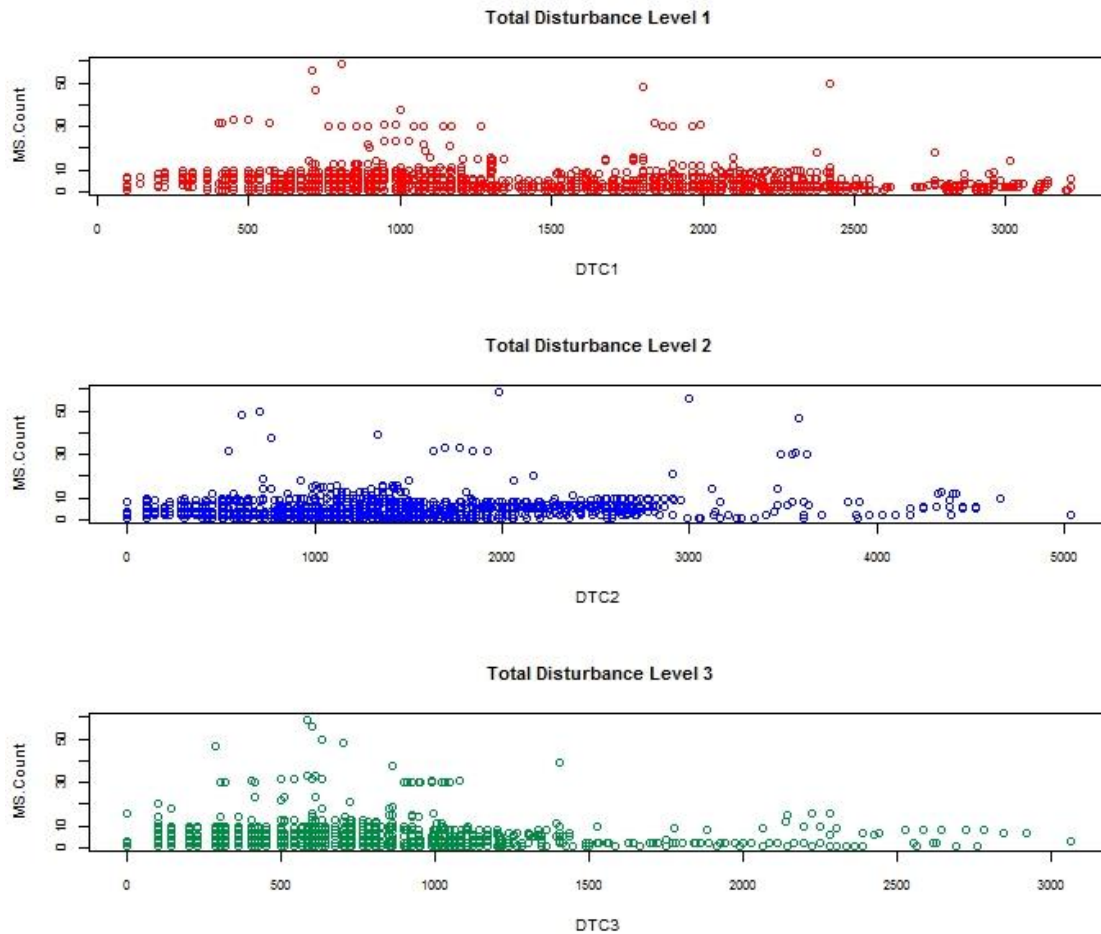


Figure 5.46: Mute Swan distribution associated with distance (m) to each total disturbance category (DTC1, DTC2 and DTC3).

Pre-construction this species showed a preference for occupying areas close to the shoreline; however no significant relationship was found for years during construction which is surprising given the Hurdle model results. The change in association with the shoreline represents a shift in distribution from the Central to the Main Section. Although this was observed in spatial mapping, statistical analysis for section was non-significant. This is likely due to differences in density between the two areas; a total of 6875 Mute Swan were analysed of which 89% were recorded for the Main Section in a total of 1314 Refgrid cells (over the four years). The remaining 11% in the Central Section occupied a total of 131 cells, reflecting differences in density and preferred or suitable areas between the two sections.

5.4.2.9 Great Crested Grebe

Pre-construction this species was found to favour areas of the Main Section displaying structural diversity, specifically the transitional water depth zones containing aquatic vegetation. The Western Section also supported aggregations of Great Crested Grebe whose numbers significantly increased during construction (combined months April – September, Chapter 4). As the Western Section was considered mitigation habitat, increased use may have been a result of displacement although numbers did not simultaneously decline for the Main Section.

5.4.2.9.1 Construction and waterfowl distribution mapping

To investigate any causal relationships, construction activity and Great Crested Grebe distribution were mapped and are shown for the months of April – June in Figure 5.47 and for July – September in Figure 5.48. The pre-construction preference for areas of Wigborough Bay remained, however Refgrid cells near the main dam to the north of the reservoir also held dense aggregations; an observation not made for years prior. During September, when numbers of this species at Abberton tend to peak, construction of the main dam was continuous and of high magnitude across consecutive months. The presence of clusters throughout this time suggests disturbance at this location did not cause displacement and may even be indicative of habituation. Conversely an overriding environmental factor may account for the results. Indeed, the area in question was one of the only areas for which shoreline trees were retained due to its importance as a shelter belt for other SPA species.

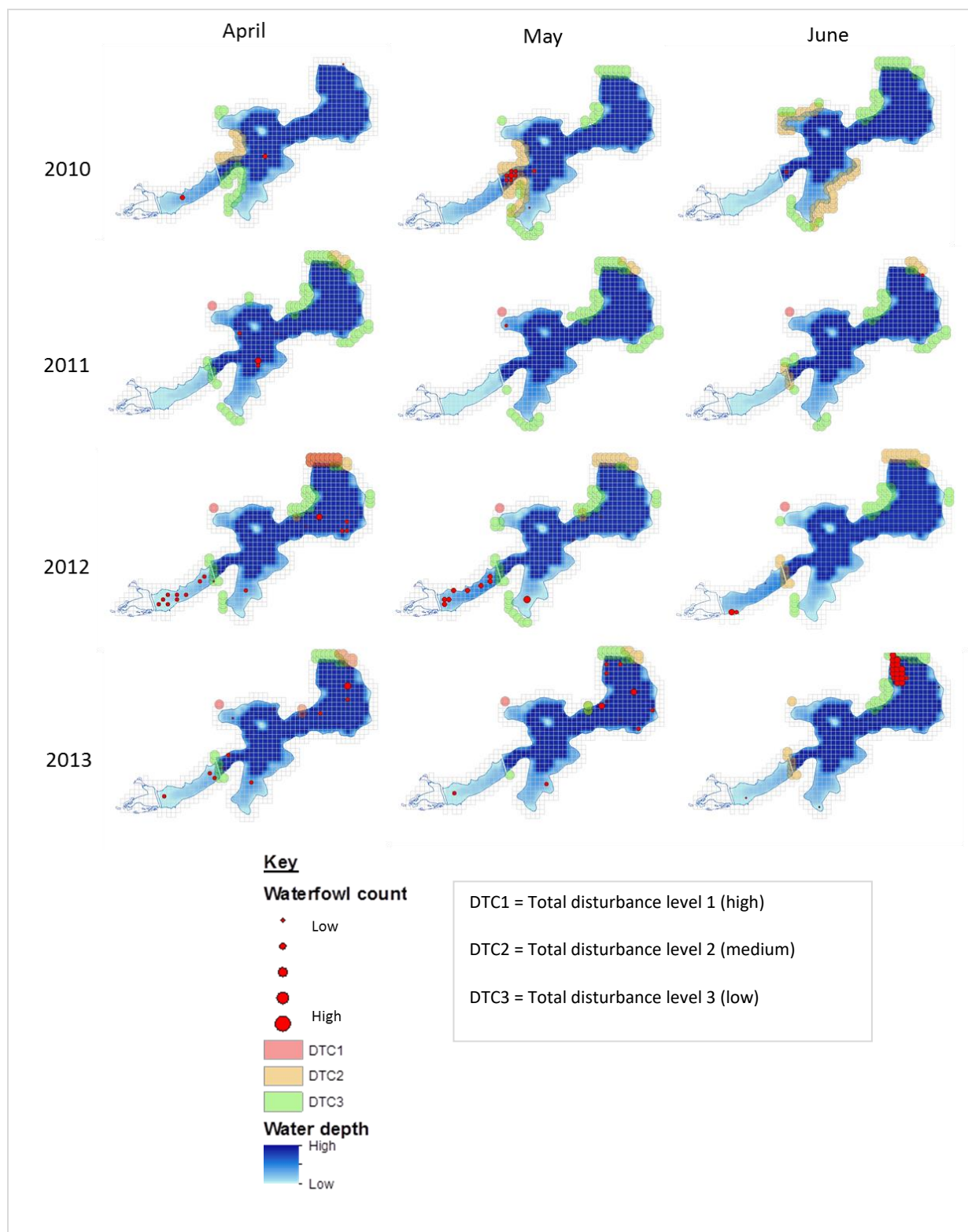


Figure 5.47: Great Crested Grebe distribution and extent of construction disturbance for months April, May and June 2010, 2011, 2012 and 2013. Counts vary each month and are represented for visual purposes on a natural breaks (Jenks) classification scale set to 5 classes and defined as low – high counts.

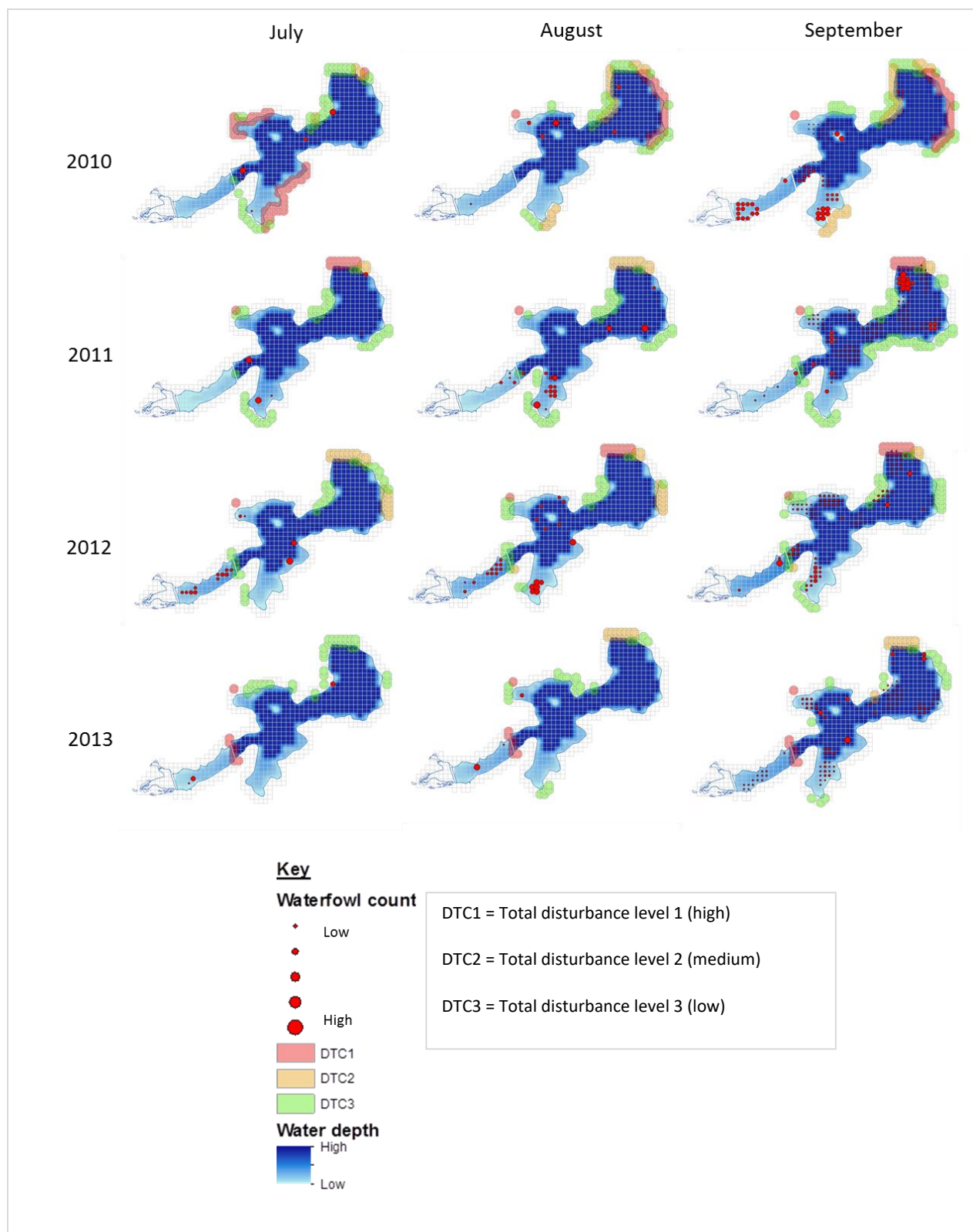


Figure 5.48: Great Crested Grebe distribution and extent of construction disturbance for months July, August and September 2010, 2011, 2012 and 2013. Counts vary each month and are represented for visual purposes on a natural breaks (Jenks) classification scale set to 5 classes and defined as low – high counts.

5.4.2.8.2 Statistical analysis

Table 5.21 provides a summary of the MAM which is more complex compared to analysis pre-construction (Part A). Environmental covariates found to be influential on numbers of Great Crested Grebe during construction were year ($\chi^2 = 7.1023$, $df = 25$, $p < 0.05$); section ($\chi^2 = 6.0136$, $df = 27$, $p < 0.01$); temperature ($\chi^2 = 22.134$, $df = 27$, $p < 0.001$); wind speed ($\chi^2 = 19.87$, $df = 27$, $p < 0.001$) and total rainfall ($\chi^2 = 9.65$, $df = 27$, $p < 0.01$). Of those, only years 2011 and 2013 were found to exert a negative influence. The positive effect of the Main Section, temperature and rainfall was found for baseline years however no relationship was previously observed for wind speed.

The negative association with some of the variables in the zero component i.e. temperature ($\chi^2 = 89.017$, $df = 26$, $p < 0.001$) and rainfall ($\chi^2 = 100.13$, $df = 26$, $p < 0.001$) reflects clustering under increasing values of these conditions - causing an increase in density across fewer Refgrid cells. The binomial component also found an increased chance of a Great Crested Grebe occurrence with increasing aquatic vegetation cover ($\chi^2 = 57.924$, $df = 26$, $p < 0.001$) and water depth ($\chi^2 = 96.356$, $df = 26$, $p < 0.001$) supporting previous findings that this species requires submerged vegetation on the edge of deep water.

Construction variables found to be significant in predicting numbers of Great Crested Grebe were DTC1 ($\chi^2 = 18.646$, $df = 26$, $p < 0.001$), DTC3 ($\chi^2 = 4.9461$, $df = 27$, $p < 0.05$); DMC1 ($\chi^2 = 8.2816$, $df = 26$, $p < 0.001$) and DMC2 ($\chi^2 = 3.0994$, $df = 26$, $p < 0.05$). With the exception of DMC2, the effects were positive with Great Crested Grebe numbers increasing with increasing distance from disturbance. None of the categories associated with distance to people-based disturbance were significant/retained in the final count model. Interpretation of the negative interaction between water depth and DTC1 ($\chi^2 = 21.989$, $df = 25$, $p < 0.001$) is that the effect of distance from construction (category 1), decreases at increasing water depths; logical since the deeper water at Abberton Reservoir tends to be at distances further from the shoreline and occurrence of this species is associated with deeper water.

Table 5.21: Summary table of Hurdle model results for Mute Swan in years during construction. Only variables with a confidence level of 95% (<0.05) are shown.

Variable	Z value	Significance (p-value)	Relationship
Count model (truncated negative binomial with log link)			
<i>Total construction disturbance</i>			
2011	-2.455	<0.01	-
2013	-2.519	<0.01	-
Main Section	2.412	<0.05	+
Temperature	4.859	<0.001	+
Wind speed	4.675	<0.001	+
Total rainfall	3.309	<0.001	+
Construction (DTC1)	4.304	<0.001	+
Construction (DTC3)	2.107	<0.05	+
Water depth*DTC1	-4.313	<0.001	-
<i>Machine construction disturbance</i>			
Construction (DMC1)	6.927	<0.001	+
Construction (DMC2)	-2.170	<0.05	-
Zero hurdle model (binomial with logit link)			
2011	3.556	<0.001	+
2012	7.412	<0.001	+
2013	5.594	<0.001	+
Main Section	-7.424	<0.001	-
% macrophyte	7.297	<0.001	+
Water depth	8.324	<0.001	+
Temperature	-6.981	<0.001	-
Total rainfall	-6.277	<0.001	-
Construction (DTC1)	-9.532	<0.001	-
Construction (DTC2)	4.085	<0.001	+
Construction (DTC3)	-7.592	<0.001	-
% macrophyte*water depth	-6.621	<0.001	-
Temperature*total rainfall	4.392	<0.001	+
<i>Machine construction disturbance</i>			
Construction (DMC1)	-5.717	<0.001	-
Construction (DMC2)	-8.319	<0.001	-
Construction (DMC3)	-4.893	<0.001	-
<i>People construction disturbance</i>			
Construction (DPC1)	-5.806	<0.001	-
Construction (DPC3)	-9.580	<0.001	-

N.B. Where * indicates an interaction

Distance from shoreline explained some of the relationships observed between construction categories and waterfowl species. Great Crested Grebe however, were not associated with distances closer to the shoreline and were evenly distributed between 50 and 550m. Figure 5.49 shows the

distances associated with this species to all three total construction categories. Although variable scales are shown, higher numbers of Great Crested Grebes are closer to the lower categories of disturbance (level 2 and 3) compared with the highest ranking construction activities. This suggests that intense construction disturbance does have a greater impact upon this species than lower intensity activities however it did not cause site displacement; a finding consistent with other Abberton Reservoir SPA species.

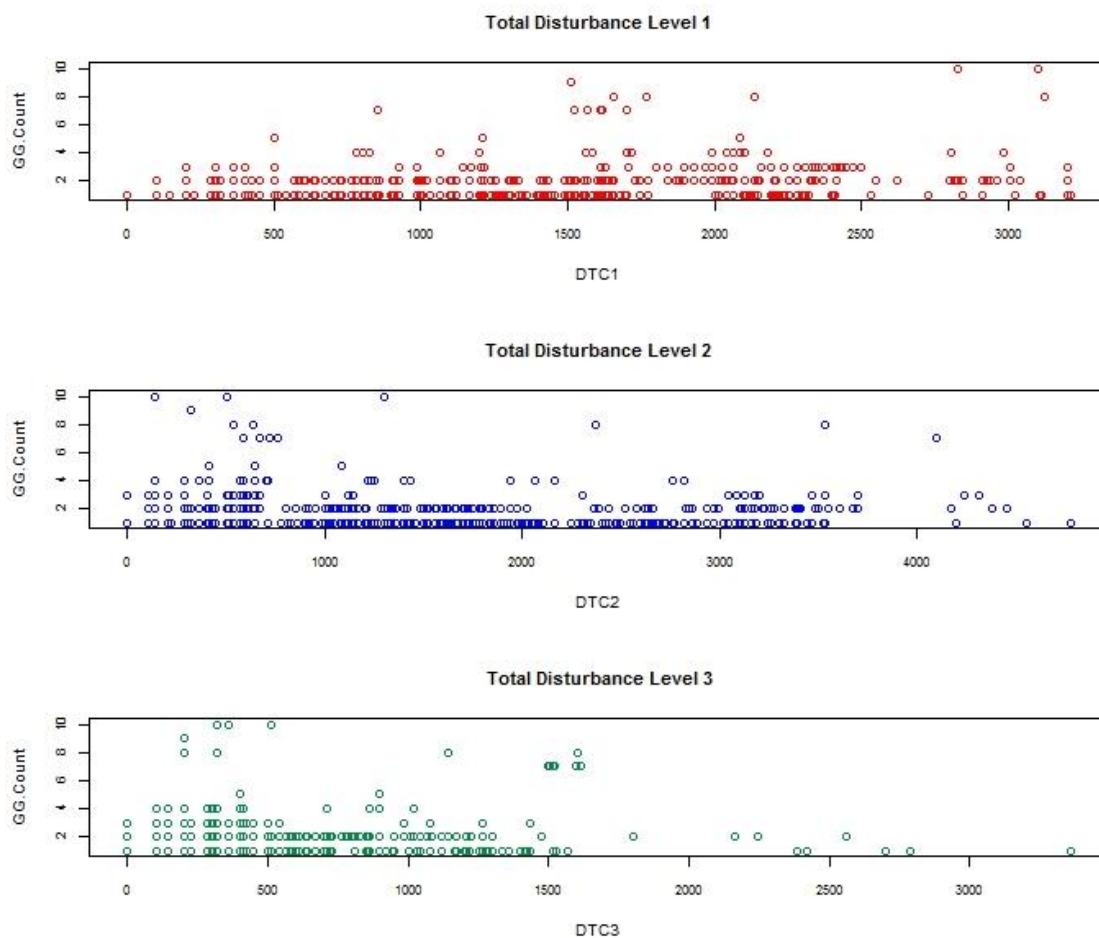


Figure 5.49: Great Crested Grebe distribution associated with distance (m) to each total disturbance category (DTC1, DTC2 and DTC3).

5.5 Discussion

5.5.1 Summary

The spatial distribution and influence of environmental variables upon nine Abberton Reservoir SPA waterfowl species was assessed for years pre-construction (2006-2009) and for years during construction (2010-2013). Analysis pre-construction (Part A), provided a baseline with which to assess impacts of construction activity (Part B). Between April and September 2010-2013, construction activity was mapped and categorised into high, medium and low level disturbance. The impact of magnitude and type of construction activity (total, machine and people based disturbance) on each species, was then assessed in combination with environmental variables. To account for the complicated and varied range of data and ecological processes occurring at Abberton Reservoir, various analytical techniques were used including Hurdle model analysis, bivariate linear modelling and spatial mapping.

Results show that across all years, the most influential environmental variables upon the distribution of waterfowl species at Abberton Reservoir were water depth and macrophyte cover. Findings support those presented in Chapter 4, with results suggesting that changes to the reservoir resulting from construction activity were of particular benefit to the dabbling duck species. Numbers increased and distributional shifts from the Central and Western Sections to the Main Section were observed; likely due to the increase in available shoreline habitat resulting from shoreline re-profiling. Additionally, results suggest that the shift of waterfowl from the Central Section may have been a disturbance response with effects more pronounced on the smaller section, particularly since the majority of species were shown to maintain a distance of 200m away from construction disturbance. That said, some species such as Teal, whilst showing sensitivity to high levels of construction disturbance, also provided evidence of habituation to constant sources of construction activity.

5.5.2 Gadwall

The spatial distribution pattern of Gadwall changed from a predominantly random pattern pre-construction to one of a more clustered nature during construction. Clustering was evident across the eight year study period for the months of August and September and reflects increased site use during this time. A significant increase in numbers of Gadwall during the construction period was reported for the Main Section in Chapter 4 and is the likely reason for the change in spatial distribution. It is also likely that increased spatial autocorrelation was a response to construction disturbance or to changing site conditions.

To assess the responses to construction disturbance, statistical analysis using Hurdle models was applied to data across the study period (2006 – 2010). The pre-construction model was used to determine environmental parameters accounting for waterfowl distribution and provided a baseline for disturbance assessment. The same environmental variables were included in all model analyses and results used to investigate if changes in species distributions were attributable to construction activity or habitat conditions.

Results showed that pre-construction, numbers of Gadwall declined with increasing macrophyte cover which was surprising since Gadwall are typically associated with sites containing high levels of submerged vegetation (Fox and Salmon, 1989). During 2006 – 2009, this species utilised the Central Section to a far greater extent than the Main Section with the latter shifting to a positive predictor variable during construction. It is likely the removal of the concrete apron and the re-profiling of the shoreline to a more natural slope enabled this species to utilise a habitat that did not exist pre-construction. Indeed Gadwall have been shown to adjust their site preferences and patterns of site use in response to changing environmental conditions (Briggs et al., 2012).

For years 2006 – 2009, a strong negative linear relationship was observed for Gadwall and distance to the shoreline. This was shown to be due to aggregations of Gadwall directly on the edges of the

reservoir and is suggestive of roosting behaviour. This observation also explains the negative relationship observed with % macrophyte since the edges were largely exposed (Central Section), concrete (Main Section) and therefore lacking in submerged vegetation. The relationships and Hurdle model results observed during construction required a little more investigation. Results indicated a shift away from the shoreline which in addition to providing roosting habitat, were likely to have contained washed up macrophyte material; a convenient food source for this dabbling duck species (Briggs et al., 2012). Movement away from the shoreline suggested a disturbance response however the increase in numbers using the Main Section, where construction activity was most pronounced contradicts this. In addition, no discernible pattern was noted in the response by Gadwall to type and magnitude of construction activity.

Unsurprisingly, Gadwall were found to be associated with areas of the reservoir containing shallow water habitat. Water depth plays a role in shaping water bird communities (Clipp et al., 2017) and many studies cite it as a key wetland variable affecting the distribution and diversity of waterfowl e.g. (Holm and Clausen, 2006, Ma et al., 2009, Tavares et al., 2015, McEvoy et al., 2016). Hurdle model findings are largely explained by the increased use of the Main Section and a preference for the island, Wigborough and Hide Bay. These areas contain shallow water habitat but the topography is such that they are not particularly close to the shoreline. This is also proffered as an explanation for the variable results to construction activity.

The overarching view is that activities did not deter Gadwall from the Main Section due to the distances involved and the ability to locate to undisturbed parts of this section; likely due to the sensitive programme design. There is however an argument for a more pronounced disturbance response resulting from causeway works on the smaller, more homogeneous Central Section. This is supported by evidence that Gadwall generally maintained a distance of 200m from construction, the perceived magnitude of which may increase on smaller, more uniform waterbodies. This may have reduced the carrying capacity of the Central Section with waterfowl no longer associating it with safe

roosting or foraging habitat. In reality, the results presented are likely due to a combination of factors, with Gadwall increasing their distance from the shoreline due to construction activity yet overall site suitability being maintained due to abundant food and increased opportunities in the Main Section.

5.5.3 Shoveler

Pre-construction, Shoveler were absent from the Main and Central Sections in a total of nine monthly waterfowl surveys (during April - September). During construction, a zero count was recorded only once which reflects the increase in Shoveler at Abberton in years 2010-2013 compared with 2006-2009. Hurdle model analysis for the pre-construction period found year to be the only significant variable influencing numbers of Shoveler, whereas five environmental covariates in addition to disturbance variables were significant during construction.

One benefit of fitting a Hurdle model to zero-inflated count data is that information can also be gleaned from zero observations; particularly useful when there are few variables accounting for variation in the count component. Pre-construction, increasing wind speed, rainfall and water depth were all associated with the prediction of a zero outcome i.e. no Shoveler. The relationship with these variables was even stronger during construction as they appeared in both the count and zero model components. This suggests that at Abberton Reservoir, changes in these conditions are particularly influential on numbers and distribution of Shoveler.

Aggregations were also found to be associated with shallower water although bivariate linear modelling did not reveal any significant relationship suggesting they can utilise a range of water depths. Indeed the extent of water depths waterfowl will utilise depends on foraging behaviour (Isola et al., 2000) and Shoveler can adapt, dabbling at the surface but also up-ending/tipping to reach prey at slightly deeper depths. Food abundance of which zooplankton is favoured has been found to be important in habitat selection for this species (Guillemain et al., 2000a, Briggs et al.,

2012). Abberton Reservoir is a fairly exposed site and results presented here suggest that increased rainfall and wind speeds disrupt the feeding pattern of this species which is likely to reduce foraging activity.

Results suggest that Shoveler were more dispersed in the Main Section during construction, occupying a greater range of water depths and distances from the shoreline. Increased numbers and their principal foraging technique, filter feeding along the surface of the water, may account for this distribution pattern. It also explains the association of a Shoveler count occurrence with increasing macrophyte cover since areas of dense vegetation are those of open water in depths less than 3m. Zooplankton is also higher where vegetation is present. These observations suggest Shoveler spent much of their time during construction foraging which may be a behavioural response to disturbance. As the level of disturbance increases, an animal has to sacrifice some of its time spent resting in order to increase the time spent foraging and responding to disturbance (Houston et al., 2012). Similar to Gadwall, overall numbers increased for the Main Section during construction therefore disturbance on this section at least, did not cause displacement. Additionally, Shoveler are known to actively move between nearby sites and within a water body, presumably a strategy to account for fluctuations in zooplankton and increase food security (Briggs et al., 2012). The ability to move between areas would easily enable Shoveler at Abberton Reservoir to disperse to other nearby sites if impacts of disturbance exceeded site benefits. Of course this does assume individuals are fit enough to move and that the other sites frequented by Shoveler are undisturbed with an abundance of food. Should this not be the case, a trade off would be necessary and their tolerance to disturbance may increase.

5.5.4 Teal

The extent of spatial autocorrelation exhibited by Teal varied across the months and throughout the eight years with clustering more pronounced during high count months e.g. September. Several reasons for clustering behaviour are likely including resource exploitation and predator avoidance,

the latter of which may be particularly important during the moulting period. Similar to Shoveler, fewer zero monthly counts of Teal were observed during construction compared with pre-construction supporting previous findings that numbers significantly increased during 2010 – 2013. The increase at Abberton Reservoir also coincided with a shift from this species favouring the Central Section pre-construction, to higher numbers associated with the Main Section during construction. This is likely due to the creation of shallow margins resulting from shoreline re-profiling and the larger section being able to support more waterfowl.

Dabbling species generally require shallow water to forage and their access to foraging habitat is limited by water depth (Ma et al., 2009). Somewhat expectedly therefore, water depth was found to be a significant predictor of Teal with increasing depth associated with a decrease in numbers and an increase in the chance of a zero count outcome. This was observed across all study years suggesting water depth is a key environmental predictor for this species although they have been known to forage at a range of depths if required (Arzel and Elmberg, 2015).

Teal were also found to decrease with increasing distance from disturbance however it is likely that this is a product of water depth and distance to shoreline, the latter of which was shown to be highly correlated with the construction – distance variables. Several waterfowl species are shown to be positively associated with the shoreline which is thought to be linked to food exploitation or availability of suitable roosting sites (Pap et al., 2013). There is some evidence to suggest there is a threshold distance to extensive construction with relatively few Teal being present within 200m of high disturbance events. Indeed, Teal are thought to be one of the most sensitive species to disturbance moving away or taking flight when the source of disturbance is close (Tuite et al., 1984). Results therefore suggest that the effects of disturbance may have been limited due to the size of the reservoir and the phased construction timetable with Teal finding sufficient resources at distances where shoreline disturbance did not cause displacement.

Further to this, results also suggest the possibility of Teal exhibiting a degree of habituation since many of the high magnitude disturbance events were associated with construction events whereby activity was consistent, sustained and limited in extent. This is supported by the map outputs showing that this species avoided areas with less predictable, lower impact disturbance events covering a greater extent. Given the size of Abberton Reservoir however, the distances involved and the variability of waterfowl distribution across each month it is difficult to confirm this theory with the analyses presented here.

5.5.5 Wigeon

The general view is that numbers of herbivorous waterfowl in Europe have increased substantially over the last 50 years (Fox et al., 2010) which may be due to more restrictive hunting legislation and increased site protection. However, there is now evidence to suggest that European Wigeon have shown some decline since the mid 2000's (Fox et al., 2016, Poysa et al., 2017). At Abberton Reservoir, numbers significantly increased during construction and Hurdle model results showed higher numbers of Wigeon were associated with the Main Section. This was not found for years pre-construction where the Main Section was linked to the prediction of a zero count. Across all years and in particular 2010, Wigeon were present in the Central Section to a greater extent than other dabbling species although pre-construction analysis was largely limited to August and September since counts were zero for many other months.

High numbers in the Central Section during 2010 and 2011 coincides with the first few years of construction and amongst other re-profiling activities, the breaking and removal of the concrete apron directly on the shoreline. Wigeon are herbivores largely feeding on grassland in close proximity to water (Mayhew, 1987) and have a requirement for long undisturbed feeding periods (Mayhew, 1988). The observed distribution of Wigeon during this time implies that construction activities in 2010 had a greater impact than in subsequent years. This may have been directly caused by disturbance since species requiring large areas or continuous foraging may be more susceptible to

shoreline disturbance (Schummer and Eddleman, 2003). The effect was likely to have been exacerbated due to the removal of available grazing areas resulting from the re-profiling. Based on the same reasoning, it is likely that the creation or retention of feeding areas for this species during construction would have been of benefit.

Having said that, overall, numbers of Wigeon during construction increased within the Main Section. These birds were in close formation, at approximately 200m of the shoreline and in areas containing shallow water; a consistent determinant across all study years. This suggests that the disturbance response primarily affected their foraging which may have been compensated for by increased feeding during quieter periods (Schummer and Eddleman, 2003), or by feeding in undisturbed areas and increased day roosting. In addition, the relationships found between type and magnitude of construction disturbance and this species suggest that specific events, not necessarily an overall disturbance magnitude were perceived as greater threats. It could also be reflective of differing responses with reactions less pronounced after a degree of habituation or when bird densities are lower. All are plausible theories with their own merits however further investigation is required to determine whether one is largely responsible. It is likely, given the complexity of site and varying environmental and construction conditions, that a combination of factors is responsible for the results reported; inevitably these all influence how a bird perceives and subsequently reacts to disturbance (Blumstein, 2005, Livezey et al., 2016).

5.5.6 Coot

Throughout the study period, Coot displayed a high degree of clustering and were only absent from one monthly survey (July 2007). As reported in Chapter 4, Abberton Reservoir is the top site in the UK for this species with numbers typically exceeding that of any other. Counts were consistently high each September, coinciding with aggregations building up in large bodies of freshwater for the autumn moult (Calbrade et al., 2010). Generally, numbers were highest during construction with annual counts for months April – September averaging 13,794 (9394 pre-construction). The

exception was during September 2009 when numbers within the Main and Central Sections exceeded 12,600.

The high degree of clustering observed during the moulting period explains the initially conflicting pre-construction Hurdle model results; the effect of increasing temperature and wind speed were reported as positive in the count model yet negative for the binomial component. This spatial autocorrelation is due to numbers of Coot being more densely aggregated and spatially constricted in higher winds and during late summer when temperatures are generally higher. It was also noted that the Hurdle models for Coot were more complex compared to the dabbling species. It is possible a missing covariate is responsible however it is more likely that this species can utilise a wider range of habitats compared to the dabblers due to their ability to dive.

Across all years, numbers of Coot decreased with increasing water depth however they were found in slightly deeper water pre-construction. In addition, no significant relationship with distance to the shoreline was observed during construction suggesting they did not re-distribute to deeper water in response to disturbance. This differs from studies reporting that Coot fed in deeper water in response to hunting disturbance (Holm et al., 2011) and land-based vehicles and natural disturbances caused an increase in flight response (Schummer and Eddleman, 2003). This suggests that type of disturbance is important to this species' threat perception. It is also highly likely that the size of wetland, extent of disturbance and feeding requirements all influence the response elicited by a species or individual. Results presented here largely indicate that at a site level, Coot were not impacted by construction activity however it is difficult to determine if there were any effects at a population level (Hockin et al., 1992a).

5.5.7 Tufted Duck

Across all years, Moran's I statistic reported a predominantly clustered distribution pattern and with the exception of July 2007 and 2009 this diving duck species was recorded in every monthly

waterfowl survey. For combined months April – September, annual numbers of Tufted Duck were over 20 times more variable in years pre-construction with large aggregations notable for the Main Section during September 2008. During construction, Tufted Duck showed a significant decline for Abberton Reservoir (all three sections combined) and the Central Section during construction (October – March (Chapter 4)). The decline appears to have been specific to Abberton Reservoir since numbers at other key sites were stable with some even reporting higher than average counts (Austin et al., 2008).

It is possible the decline was attributable to disturbance although construction activity during the winter period was reduced to a few continuous activity areas such as building of the Main dam and offtake-pumping station. Causality is somewhat difficult given the uncertainty of independence and the fluctuating nature of waterfowl however they may learn to identify particular sites with disturbance and avoid them (Madsen, 1985). In addition, ringing recoveries from Abberton Reservoir suggest that Tufted Duck show site fidelity and return in subsequent years (Fox and King, 2011) supporting the disturbance theory. Spatial mapping and Hurdle model analysis provides further evidence with aggregations located away from high impact disturbances which, similarly to other species was exaggerated on the smaller Central Section. Sensitivity of this section to disturbance may also account for the Main Section being a positive predictor variable.

The Main Section was also likely to have been attractive to Tufted Duck, not only because of its larger size but due to the abundance of deep water, which this species was found to be positively associated with. Diving species such as Tufted Duck tend to aggregate in inland waters where they utilize the benthic resources (Oka et al., 1999). This gives Tufted Duck an advantage at sites such as Abberton Reservoir as they are able to exploit resources unavailable to other species. In addition to chironomid larvae, molluscs are a favoured prey item (Winfield and Winfield, 1994, Stewart and Lauder, 1997) and Tufted Duck forage up to 5m to obtain them (Leeuw et al., 1999). Food preferences may explain the positive relationship with macrophyte beds since aquatic vegetation

provides habitat for a range of prey species including molluscs. Results also showed wind speed and temperature to be consistent predictor variables for aggregations of Tufted Duck. Temperature is explained by higher counts occurring in the warmer months of August and September and the relationship with wind suggests increasing speeds promotes clustering behaviour; presumably because it reduces energy expenditure. Although unsubstantiated, there are reports of diving Duck species using aquatic vegetation as an anchor, particularly on open sites and in high wind further highlighting the importance of a healthy diverse aquatic ecosystem.

5.5.8 Pochard

The Common Pochard is the UK's fastest declining duck species which now sees it on the IUCN Red List (Calbrade et al., 2010, Eaton et al., 2015). Although the decline has been occurring steadily over time we take some assurance that numbers at Abberton Reservoir have not significantly changed. Across all eight years and according to Moran's I statistic, the observed monthly distribution was variable and reported as both random and clustered.

Pre-construction, similarities in spatial distribution were noted between this species and Tufted Duck. Both are classified within the diving duck guild however the diet of Pochard is more omnivorous and it is reported that they tend to feed and roost on different water bodies than Tufted Duck (Fox and King, 2011). Pochard have also been found to more readily move to other areas when animal foods become less abundant (Sekiya et al., 2000). Given the largely similar distribution pattern, the expectation was for statistical analysis to report the same influential variables however this was not the case. It was also surprising that water depth did not influence numbers of Pochard in either study period and was only found to be significant in the prediction of a Pochard occurrence (as opposed to a zero count) during construction.

One notable difference between pre and during construction was the relationship with aquatic vegetation and the distance of aggregations to the shoreline. Pre-construction, clustering was most

pronounced at increased distances and a negative relationship with increasing macrophyte cover was observed; logical since growth of submerged vegetation is limited by depth and shallow water habitat is associated with areas closer to the reservoir edge. This shifted during construction with aggregations located closer to the shoreline amongst Refgrid cells containing dense vegetation. There are several possible reasons for this however given the study subject; the two offered here are consequences of disturbance and one is considered more detrimental. The first theory concerns a distributional shift away from areas subject to disturbance, the result being Pochard were located closer to the shoreline in parts of the reservoir where construction was absent. In these locations Pochards still found sufficient food resources and roosting was not interrupted. The second is also a disturbance response but is considered more detrimental because the balance between foraging and roosting was altered; possibly caused by increased vigilance in response to construction activity. To address any energy deficits, Pochard likely spent more time foraging during quieter times; a finding reported in waterfowl by Schummer and Eddleman (2003).

Without further analysis it is difficult to accept one theory over another however, sustained disturbance typically results in habituation, tolerance or site displacement. There is no evidence to suggest Pochards were displaced from Abberton Reservoir but spatial analysis does suggest Pochard habituated to disturbances of a constant, more predictable nature such as those associated with the building of the off-take pumping station and the main dam.

5.5.9 Mute Swan

Unlike other analysed SPA species, numbers of Mute Swan at Abberton Reservoir peak in April – September. Spatial and statistical analysis support previous findings (Chapter 4) that Mute Swan are highly dispersed throughout Abberton Reservoir.

The UK Mute Swan population is largely sedentary comprising two discrete populations (Rowell and Spray, 2004). They also display a high degree of site fidelity which is one explanation for the ability of

this species to become habituated to disturbance. Habituation appears more common in larger bodied species and is linked to energy expenditure; when birds fly off after a disturbance, they use extra energy that subsequently needs to be compensated (Nolet et al., 2016) and the energy required for flight in a bird the size of a swan is significant. Results here support tolerance or habituation as the Hurdle model did not find any differentiation between type and magnitude of construction activity; in fact, numbers were shown to decrease with increasing distance from disturbance events. The distance between bird and construction was however greater for high impact events which may be a disturbance response or be reflective of locality given the size of the reservoir and the extent of activity. Another spatial observation for years during construction was increased clustering and reduced use of the Central Section - the Main Section was a negative predictor variable pre-construction.

For baseline years, the presence (zero model component) of this species was strongly linked to aquatic vegetation, however, surprisingly Mute Swan aggregations were not found to be associated with macrophyte beds. This is explained by the preference for the Central Section pre-construction with Mute Swan located along the shoreline edges, presumably roosting or engaging in preening activity. Similarly, during construction, submerged aquatic vegetation was associated with a count occurrence, but not for aggregations. This finding was somewhat unexpected since Mute Swan have a strong affinity with aquatic vegetation with many studies even reporting extensive grazing damage by this species (O'Hare et al., 2007, Sandsten and Klaassen, 2008, Gayet et al., 2011, Wood et al., 2012, Wood et al., 2014). Throughout the study period submerged aquatic beds at Abberton Reservoir were abundant, species rich and contained *Potamogeton*, *Myriophyllum* and *Chara*, all important food resources for this species (Rowell and Spray, 2004). The breaking of the concrete shoreline edge and creation of nibs to facilitate re-profiling may have resulted in increased quantities of fragmented vegetation along the shoreline and explain the lack of this variable in the count model and the negative relationship with water depth. That said, no significant linear

relationship between this species and distance to shoreline was observed during construction and swans typically prefer open water (McEvoy et al., 2016).

5.5.10 Great Crested Grebe

Analysis from this study showed this species to have a preference for the Main and Western Sections with significantly more Great Crested Grebe observed in the Western Section during construction compared with years pre-construction. This initially suggests a disturbance response with displaced birds relocating to the Western Section; habitat specifically designed for this very purpose. However, if that were the case, numbers within the other two sections should have simultaneously decreased. In addition, high numbers were seen in the vicinity of the main dam during construction which was a source of constant disturbance. Of course, there may be overriding environmental conditions pertinent to that area compensating or reducing any disturbance effect. Indeed, the area favoured by Great Crested Grebes and other species contains a belt of trees offering shelter from the wind and rain. This species also requires vegetation to nest (Cramp and Simmons, 1977, Cheriet et al., 2015) and this would have been the only area within the Main Section containing suitable nesting habitat; potentially adding to its appeal. In subsequent years, the extent of emergent and submerged terrestrial vegetation increased which has been attributed to the increase in successful nesting of this species and of Coot at Abberton Reservoir.

For both study periods the binomial Hurdle model reported a strong positive association with the occurrence of Great Crested Grebe and increasing aquatic vegetation. During construction, a count occurrence was also associated with increasing water depth and for all years, the interaction between macrophytes and water depth was significant. Spatial mapping showed this species to be primarily located on the periphery of deep water and together with statistical analysis suggests that areas containing aquatic vegetation in the transition zone between shallow and deep water are highly important to this species. Aquatic vegetation is an important ecosystem component and many studies have indicated a strong correlation between vegetation structure and bird diversity (Erwin

and Beck, 2007). Macrophyte beds not only provide direct food for herbivorous waterfowl species but they create structural diversity and maximise the habitat for fish; the primary food for Great Crested Grebe. It is also likely that these deeper areas, away from the shoreline contained clear water as prey may be more difficult to detect when water is turbid (Gawlik, 2002). This may also facilitate flock-fishing which has been reported in this species (Kallander, 2008).

Habitat connectivity plays an important role in species and ecosystem ecology; indeed it is one of the objectives of Natura 2000 sites. For some species, foraging across a variety of wetlands is more effective than remaining at a single site (Craig and Beal, 1992) and waterfowl at Abberton Reservoir are likely to also utilise the nearby coastal habitat. The ability to move between neighbouring sites such as the coast and Abberton Reservoir enables individuals to obtain sufficient resources and to quickly relocate should conditions at one turn unfavourable. Along with increased clustering behaviour, this is one explanation for the observed positive relationship between Great Crested Grebe and covariates such as wind and rain; conditions would likely be worse on the coast and inland sites would provide a degree of shelter. This theory also applies to other species frequenting Abberton Reservoir such as Teal which are known to move between the coast and Abberton Reservoir.

5.6 Conclusions

A combination of spatial distribution mapping, Moran's I measure of autocorrelation and Hurdle model analysis was used to determine the effects of environmental variables and construction activity on nine Abberton Reservoir SPA species. Waterfowl data for months April through to September, representing the time during which the majority of construction activity occurred, were analysed for year's pre-construction (Part A) and during construction (Part B). Data for the Western Section were excluded since this section was termed the mitigation habitat and is analysed in Chapter 6.

Overall, results show that construction activity caused limited waterfowl displacement from the Main Section however distinct differences between species were observed. The most consistent findings were a reduction in occupancy of the Central Section, the importance of aquatic vegetation and that waterfowl maintained a distance of 200m away from construction activity. The observed decline for the Central Section is attributed to increased use of the Main Section and disturbance associated with the causeway raising. Previous disturbance studies have found that the magnitude of response is inversely related to the distance between bird and source of disturbance (Pease et al., 2005, Western et al., 2012) however results presented here also indicate a threshold distance of 200m. The relevance of aquatic vegetation at Abberton Reservoir supports existing literature linking increased waterfowl abundance with wetland vegetation (Froneman et al., 2001, Bancroft et al., 2002).

The dabbling duck species appear to have immediately benefited from the enhancement works as numbers significantly increased within the Main Section during construction. This is likely due to changes in shoreline topography with re-profiling works creating additional areas of shallow water; habitat that would have optimised foraging behaviour. This is supported by Hurdle model analysis showing that Gadwall, Teal and Wigeon were positively associated with shallower water depths.

Interestingly, whilst the Main Section was shown to be a positive predictor variable for Wigeon, results indicate a particular sensitivity to disturbance with counts higher for the Central Section during 2010 and 2011. These years mark the start of construction at Abberton Reservoir and when removal of the concrete apron and major shoreline re-profiling works occurred; activities anticipated being most disturbing. Additionally, there is evidence that Wigeon reacted to certain activities as opposed to magnitude alone suggesting that this species requires particular consideration when assessing and mitigating for disturbance impacts.

Analyses suggest that whilst those species less restricted to the shallows were unaffected in terms of habitat change, they were arguably impacted by construction activity. This is particularly evident for Tufted Duck which were shown to move away from high impact disturbance events and reduce occupancy within the Central Section. Previous analysis also reported a significant decline for the overwintering period during construction which may be caused by this species identifying particular sites with disturbance (Madsen, 1995). Whilst a disturbance response is noted, results are also likely to link to increased opportunities during construction for dabbling duck but not for divers. Looking ahead, once the water levels are raised the extent of open water habitat will increase and assuming populations elsewhere are stable, numbers of diving waterfowl at Abberton Reservoir are likely to show the same increase as reported here for dabblers.

Whilst results suggest certain species, and not necessarily those anticipated, may be more sensitive to disturbance, spatial mapping indicated the island and the two areas of Wigborough and Hide Bay were especially influential for Abberton waterfowl. These locations are exposed at lower water levels and provide safe roosting habitat. Where wetlands provide roosting sites for waterfowl, densities tend to be higher (Hattori and Mae, 2001) therefore it is logical that structurally diverse sites, providing roosting areas, shallow and deep water are those supporting the greatest diversity and densities of waterfowl. Given this, a range of environmental variables were included in statistical analysis and as anticipated, water depth was particularly influential for the dabbling species,

especially Teal. One of the more surprising results was that diving species were linked to aquatic vegetation to a greater extent than some of the more herbivorous species. A methodological reason possibly accounts for this result; each Refgrid cell covers 100m² and should a portion of that cell cover the reservoir edge or land, by proxy it will contain less macrophyte cover than another cell consisting 100% of water. However, the association is also logical since vegetation provides habitat for a range of prey items including molluscs and chironomid larvae; important prey items for diving species such as Tufted Duck (Winfield and Winfield, 1994, Stewart and Lauder, 1997). In addition, dabbling species were probably feeding on fragments of vegetation along the shoreline. This would have been magnified during construction due to the creation of nibs and re-profiling activities increasing the diversity and crinkliness of the reservoir edge. The sheltered nature of this habitat and the trapping of plant and insect material created ideal foraging habitat. The finding that submerged vegetation is also highly important to Great Crested Grebe, whose diet is piscivorous is significant. Evidence indicates that at Abberton Reservoir, this species occupies the transitional zone between shallow and deep water where it is likely the structural diversity increases prey abundance. These areas are also likely to contain clear water as shoreline activities likely caused a degree of shoreline erosion and increased turbidity within the vicinity of works.

Hurdle model results for type and magnitude of construction disturbance were variable and it should be noted that even in areas not disturbed by planned construction activity, incidental disturbance by members of the construction team, trespassers or natural predators inevitably occurred and in this instance, could not be accommodated for. However, given sample sizes and significance levels we can be confident in results showing that some species, including Great Crested Grebe showed some response to magnitude of construction disturbance, moving away from areas of high impact disturbance. Others, such as Teal and Pochard displayed evidence of habituation where the disturbance was more consistent and predictable. The fact that numbers of Pochard have remained constant throughout the study period is also of relevance considering this species has shown a dramatic decline in recent years.

Crucially, despite evidence that construction activity caused a disturbance response in some species, it did not cause site displacement; shown by increased or consistent numbers of species in the Main Section during the active construction period. The exception was during August 2013 where there was a distinct lack of waterfowl compared to other years. Reasons for this are currently unknown and require further investigation. Although many factors contributed to the Main Section maintaining or increasing numbers of waterfowl during construction, there is no doubt that habitat diversity and the sheer size of the site acted as a mitigating factor. This is crucial for projects with the potential to detrimentally affect waterfowl and highlights the importance of individual site assessment. A smaller, more homogeneous site is likely to suffer significant disturbance effects compared to a large and diverse one and evidence of this is provided by the impacts seen on the Central Section. It also highlights the importance of a healthy aquatic system where food is abundant; again this may in itself act as a mitigating factor and means any disturbance resulting in energy expenditure can quickly be replenished. Given this, and findings from previous studies, it is likely winter construction activity at Abberton Reservoir and indeed at other key overwintering sites would have been detrimental and resulted in waterfowl leaving the site or otherwise being negatively affected.

Chapter 6

Efficacy of displacement habitat creation and mitigation measures

6.1 Introduction and aims

Environmental Impact Assessment (EIA) is a process that assesses the potential environmental impacts of a proposed built development prior to a planning decision (Drayson et al., 2017). The EIA report (the Environmental Statement (ES)) typically outlines the impacts of the development and proposes mitigation measures designed to avoid, reduce or compensate for any identified impacts. Whilst the term mitigation is used in this research with respect to “the Abberton Scheme” overall, the Abberton Scheme ES concluded “that there is not likely to be a significant effect on the Abberton Reservoir Special Protection Area (SPA) as a result of the Abberton enhancement on its own or cumulatively with other plans or projects, having regards to the site’s conservation objectives”. This conclusion was arrived at as a result of an extensive empirical study (summarised in the Abberton Scheme Study To Inform an Appropriate Assessment (STIAA)), commissioned by Northumbrian Water Group (NWG) to assist in the consideration of the Abberton Scheme and to assess the proposals effects on the integrity of Abberton Reservoir waterfowl populations. Any potential impacts were then to be avoided and mitigated for, through the incorporation of design features, programme restrictions and habitat creation. Analysis identified three species, Gadwall, Shoveler and Teal, most at risk from shoreline construction activities and determined, based on a worst case scenario in terms of disturbance exposure, that 4ha of additional habitat created at the Western Section (see Section 6.3) would sufficiently accommodate any displaced birds. Therefore, although regarded as mitigation habitat and assessed as such, the creation of wetland at the Western Section was incorporated into the Abberton Scheme and therefore not required as compensation or mitigation for habitat loss.

Additionally, the Abberton Scheme STIAA highlighted a need for displacement habitat to be created in advance of the construction phase to ensure it was of sufficient maturity to accommodate any displaced birds. However, mitigation does not typically occur until after the project has been permitted (Strager et al., 2010) and this therefore raises a pertinent point summarised by Atkinson

(2001); if we cannot determine in advance whether a mitigation scheme will be successful, it is difficult to see how the requirements of the Habitats Directive can be satisfied by mitigation that takes place at the same time as the development. It was concluded that a substantial amount of further research, including some experimental work, is required in order to evaluate the effectiveness of mitigation and management methods. This was acknowledged by NWG and stakeholders involved in the Abberton Scheme project and in October 2008, prior to planning permission being granted, creation of the Western Section displacement habitat occurred.

Although the monitoring of mitigation initiatives is critical to informing best practice, research into their success or indeed failures is distinctly lacking (Buckley, 1991, Bakker et al., 2000, McKinstry and Anderson, 2002, Drayson and Thompson, 2013). This research provides a unique opportunity to assess the approach taken by NWG and to evaluate the effectiveness and success of mitigation strategies and displacement habitat resulting from the Abberton Scheme STIAA.

The specific aims of this chapter are to:

- Determine any spatial and temporal changes in use of the Western Section by Abberton Reservoir SPA waterfowl species in years prior to and during construction of the Abberton Scheme.
- Assess the spatial and temporal use of the Western Section by Abberton Reservoir SPA waterfowl species prior to and following creation of displacement habitat.
- Determine any patterns in use of the Western Section by Abberton SPA waterfowl in relation to construction disturbance from the Abberton Scheme.
- Evaluate the efficacy of the created displacement habitat and mitigation measures in respect of construction of the Abberton Scheme.

6.2 Methods

6.2.1 Study species and data collection

To determine waterfowl use of the Western Section and efficacy of the Abberton Schemes mitigation measures, nine SPA species (Chapter 3: Table 3.1) were analysed over an eight year period. Species data were collected as part of the monthly waterfowl surveys where each waterfowl occurrence was assigned to an identifiable coded 100m² Gridref cell (Chapter 3: Section 3.1.2). Data were organised and loaded into a geographical information system (GIS) - ArcMap 10 (Esri 2010) enabling distribution data and maps to be produced and exported for analysis.

To assess changes in use of the area in relation to construction activities, data were split between years pre-construction (2006 – 2009) and those occurring during construction (2010 – 2013). To establish if any changes were attributable to creation of mitigation (displacement) habitat, waterfowl data were further categorised into pre and post displacement habitat creation. In order to account for variation in monthly counts and to maintain analytical consistency, count data were split into two temporal periods representing spring/summer (here considered April – September) and autumn/winter (October – March). The former represents months during which construction activity was most prevalent (facilitating disturbance assessment) and the latter, months considered the migratory and overwintering period.

6.2.2 Data organisation and analysis

6.2.2.1 Statistical analysis - generalized linear modelling (GLM)

All statistical analysis were carried out in R version 3.2.2 (R Core, 2015) with data exploration following the process outlined in Chapter 3: Section 3.2.3.

Generalised Linear Models (GLMs) are particularly useful when analysing ecological count data which quite often exhibits a negative binomial distribution more frequently than normal or Poisson distribution (White and Bennetts, 1996). Following data exploration and model selection (Chapter 3), a GLM with a negative binomial error distribution was found to be the most appropriate model for eight of the nine analysed species. The exception was for Great Crested Grebe where a quasi-poisson GLM provided the best fit due to the presence of under-dispersion. Variables included in each full model were species count (dependent variable) and the covariates year, month, distance to shoreline, macrophyte cover and for years during construction (2010 – 2013) a calculated value representing total reservoir disturbance.

6.2.2.2 Statistical analysis - Mann-Whitney U test

The Mann-Whitney U test is a non-parametric technique for comparing medians of two unmatched samples (Fowler and Cohen, 1996) and was used to determine differences in use of the Western Section by waterfowl pre and post displacement habitat creation. Analysis was carried out for nine Abberton Reservoir SPA species and data grouped into:

- Pre and post habitat creation (all months combined);
- Pre and post habitat creation (for the months of April – September);
- Pre and post habitat creation (for the months of October – March).

Use of Mann-Whitney U test not only was most applicable for the data but it maintained consistency in analytical techniques and comparison between analyses presented in Chapter 4.

6.2.2.3 Kernel density estimation (KDE)

Kernel density estimation (KDE) is a non-parametric method of determining the density distribution of a population sample containing X, Y co-ordinates. Using smoothing parameters, it creates a density map representative of point objects which can be combined with other layers in a multi-layer GIS database for visualisation and analysis (Bonham-Carter, 1996).

To produce the output maps, monthly species distribution data were merged in ArcMap 10 (Esri) according to the respective temporal period i.e. April – September, pre displacement habitat creation. Four temporal periods were chosen in order to represent the spring/summer and autumn/winter periods and to maintain consistency with other analyses. The split between pre and post scrape reflects the time prior to, and post displacement habitat creation.

The KDE was calculated using spatial analysis tools (density) and by setting the processing extent to the same as displayed. For consistency with the 100m² Refgrid size and for visual interpretation purposes, a search area of 100 square metres was specified. Density units on each map therefore represent density of each waterfowl species per unit area; per square metre for these analyses. For display purposes, the spatial distribution, shown as joined data (total numbers spatially joined to each corresponding 100m² Refgrid cell) and the Refgrid 'grid' were included to add a count and size context.

6.2.2.4 Refgrid cell frequency occurrence

To determine if species displayed any preference for particular 100m² Refgrid cells covering the Western Section and to attribute increased spatial extent to displacement habitat creation, the frequency occurrence for each cell was plotted. Data were organised into pre and post treatments and a bar chart created by organising the 100m² Refgrid cells by factor levels. Plots were created using R version 3.2.2 (R Core, 2015).

6.3 Abberton Scheme displacement habitat – a summary

The STIAA was carried out in respect of proposals to enlarge and enhance Abberton Reservoir. Its primary aim was to assess the proposal's effects on the integrity of waterfowl populations in order to comply with Regulation 48 of the Habitats Directive. As part of the enhancement works, to mitigate against any waterfowl disturbance during the construction phase the Abberton Scheme included the provision of displacement habitat at the Western Section of the reservoir.

A range of methods was used to collect data in order to sufficiently determine the potential effects of the Abberton Scheme and to calculate the extent and design of displacement habitat required to offset any negative effects. These included the collation and assessment of existing ornithological data (dating from 1969 – 2006), the influence of water drawdown events and additional bi-monthly waterfowl surveys. Results determined that the most relevant construction and operational activities to have a potential disturbance effect were the concrete edge removal and re-profiling, causeway raising and operation of the new water level regime (being over 3m higher in the Main Section). Due to shallow water habitat requirements and feeding strategies, it was considered that the most sensitive species, and those most likely to suffer negative effects from shoreline construction works were the dabbling ducks Gadwall, Shoveler and Teal. To quantify the number of individuals of these species potentially displaced as a result of concrete removal works (ultimately considered the most disturbing construction activity), a field trial, whereby a portion of the concrete edging was removed, was carried out. Noise levels and visible disturbance impacts, where a bird displayed a behavioral change pertaining to a disturbance response i.e. alertness, flight or swimming away, were recorded. Observations suggested that waterfowl were not disturbed within 250m when the machine (a Komatsu PC 450 excavator) was emitting average noise levels (i.e. 109dB at source but 53dB at 250m). Increased noise levels caused by the excavator hitting the concrete edge slabs generated 126dB at the source and resulted in most waterfowl within 400m taking flight. As a result of the trial and based on waterfowl spatial distribution analysis, it was determined that

the likely zone of disturbance effect was 200m from source to bird. A literature review, carried out prior to the trial as part of the STIAA study, provided further support for this “set-off” distance.

Using the 200m visibility disturbance distance, a noise disturbance zone (based on a 60dB noise contour) and maximum bird counts, the worst case scenario was calculated in terms of numbers of Gadwall, Shoveler and Teal potentially affected by concrete removal works. To determine the area of habitat required as displacement habitat as a consequence, the maximum number of birds was divided by the density of birds inhabiting the existing Western Section (totalling 15.7ha). Results determined that an area of 4ha would be required as displacement habitat for the 28 Gadwall, 11 Shoveler and 32 Teal that would potentially be displaced from the Main Section. This habitat would be available prior to the commencement of concrete removal works and throughout the time of the operational life of the enhanced reservoir. The Western Section was considered the best location for creation of the displacement habitat as it was on-site and already attractive to the citation species with large areas of water not currently utilised by waterfowl. Additionally, it was considered that creating additional shallow habitat in this area would add to the overall ecological value of the site.

Calculated density values were evaluated against those exhibited on a trial 1.05ha wetland scrape created adjacent to the Western Section in summer 2004. This exercise provided confidence that wetland habitat can be created which is capable of providing sufficient displacement habitat within a relatively short time period. The Abberton Scheme displacement habitat at the Western Section was therefore created in Autumn 2008 and designed to maximise edge and shallow water habitat (Figure 6.1); principally as a benefit to the dabbling duck citation species. Construction of the displacement habitat was split into four phases with work occurring behind the concrete barrier wall which, upon completion was breached allowing flooding of the new scrapes.

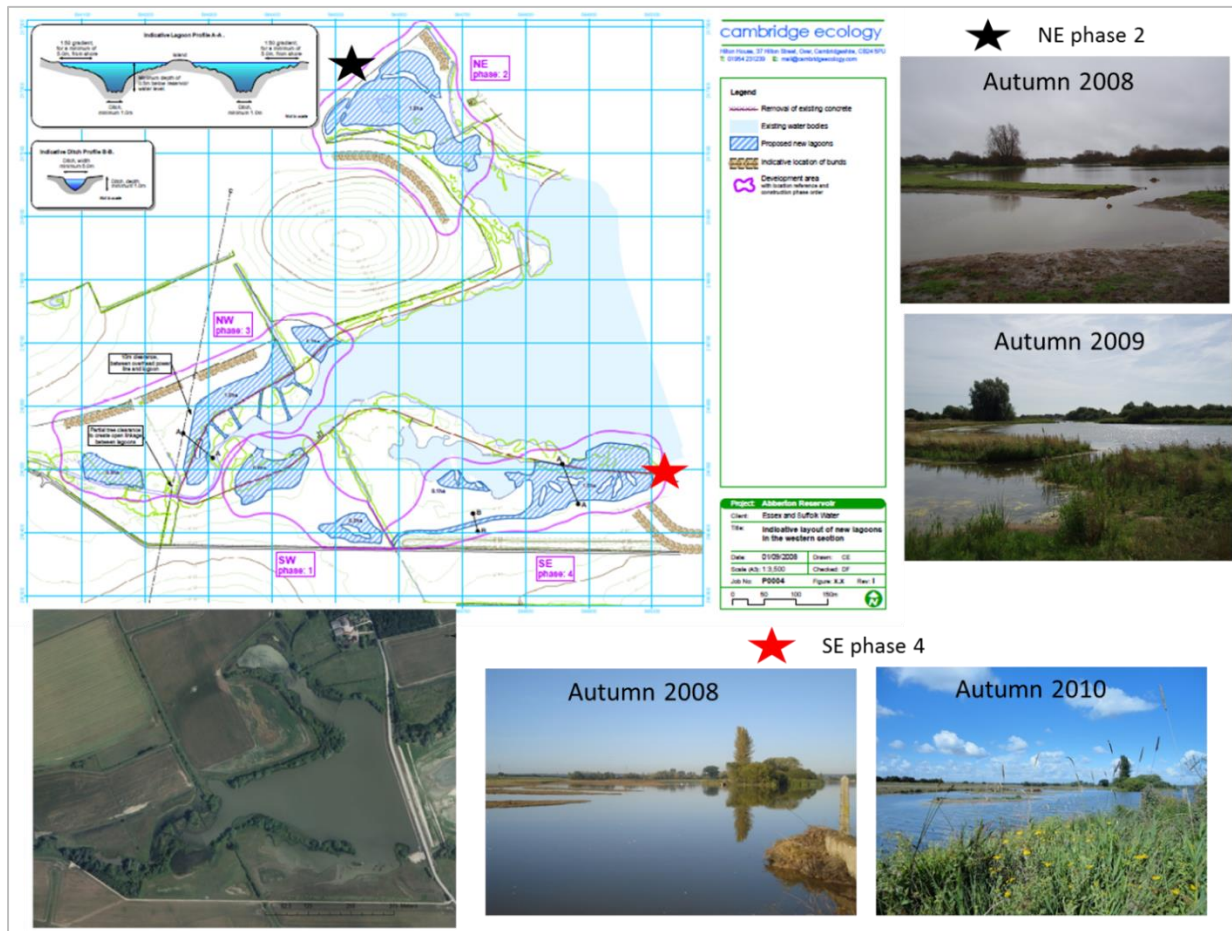


Figure 6.1: Created displacement habitat at the Western Section of Abberton Reservoir. The top left map is shown with the 100m² Refgrid system (light blue grid). The small blue hatching indicates the additional shallow scrapes created during 2008.

The concrete removal trial also provided information to assist in designing a construction programme that would cause the least disturbance to the SPA citation species. A proposed weekly construction timetable was overlaid with the 200m set-off zone and bi-weekly count data for a three year period (July 2004 – June 2006) used to calculate monthly peak numbers within the 200m disturbance area. Analysis determined that construction work should start in April and be completed by the end of September - when waterfowl numbers at Abberton Reservoir substantially increase. Additionally, the Main Section was divided into eight working areas and construction movements constrained to working in an eastward fashion around the reservoir as spatial analysis showed the western areas of the reservoir to be of high importance to waterfowl as winter progresses. For further information on the STIAA predictions and analysis refer to Chapter 2.

6.4 Results

6.4.1 Gadwall

Analysis carried out as part of this study found the Western Section to be primarily important for Gadwall during the spring/summer months (here taken to be April – September) and that although not statistically significant, higher counts were recorded pre-construction compared to years during construction. Further analysis shows that despite the lower counts, the Western Section held a greater proportion of the autumn/winter (October – March) population during construction than in years pre-construction (Figure 6.2).

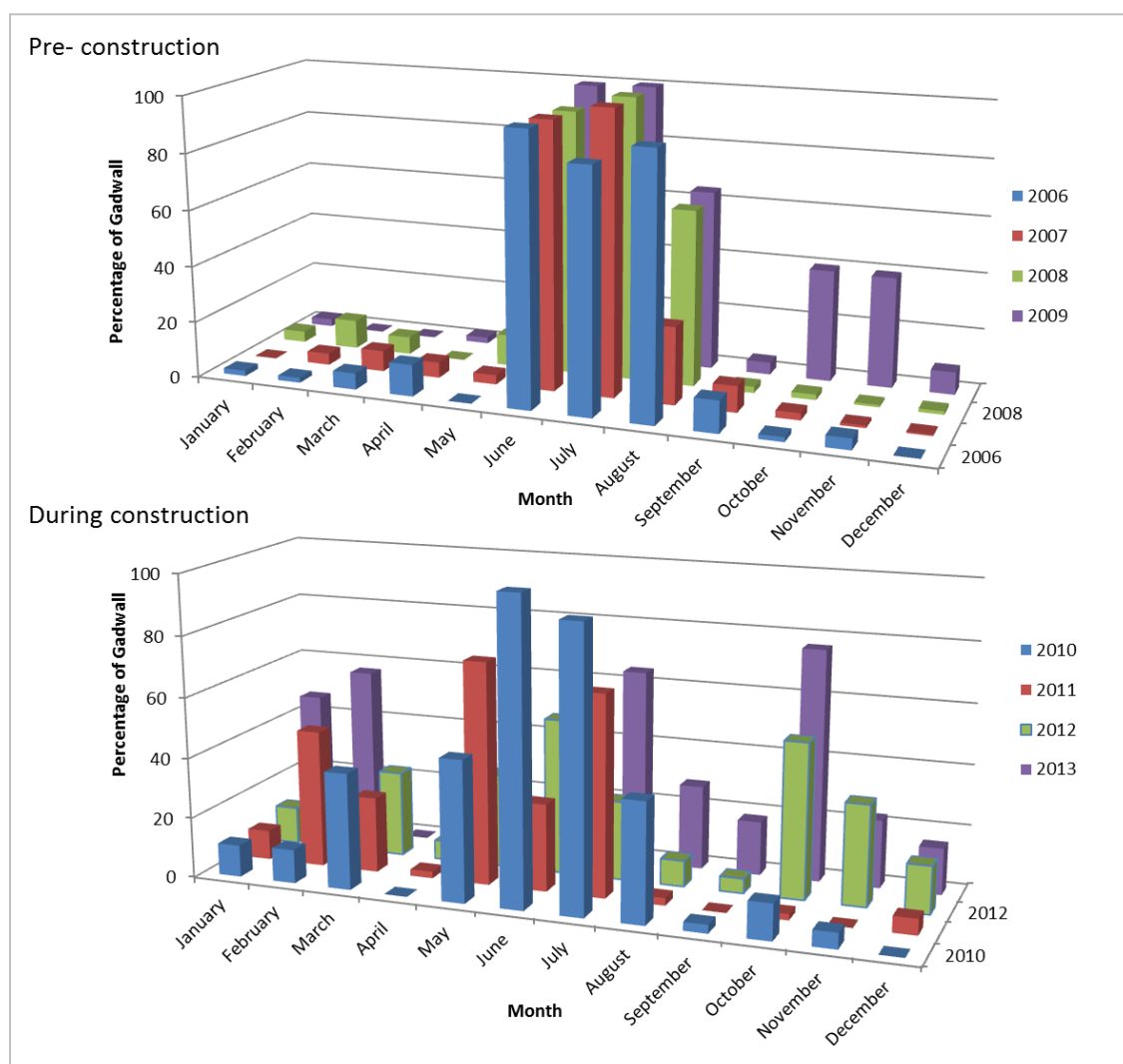


Figure 6.2: Percentage of the Abberton Reservoir Gadwall population present within the Western Section for years pre-construction (2006 - 2009) and during construction (2010 - 2013).

To investigate the differences observed in Gadwall numbers, generalized linear models (GLM) were applied to the count data. The variables year, month, species count, category of macrophyte and distance to the shoreline (shown to be important determinants of Abberton Reservoir waterfowl) were included in the full model. During the months/years of construction activity (April – September (2010 – 2013)), total site disturbance was also included as a potential covariate. Results, a summary of which is provided in Table 6.1, show that a significant negative relationship is observed between numbers of Gadwall during construction and the year 2012 for both April – September and October – March periods. Across all years, the months of July and August were consistent positive predictors of Gadwall reflecting the higher counts typically observed at Abberton Reservoir for these months. For the spring/summer months in year's pre-construction, increasing distance from the shoreline was found to be associated with the prediction of lower numbers of Gadwall. This finding is consistent with those presented in the previous chapter where this species showed a spatial preference for occupying areas of shallow water close to the reservoir edge.

Table 6.1: Summary results of GLM for Gadwall pre-construction (2006 – 2009) and during construction (2010 – 2013). Analysis split between months spring/summer (April – September) and autumn/winter (October – March).

Period	Time period	Variable	Estimate	Standard error	z value	p value	Relationship
Pre-construction	April - September	August	2.451816	0.360525	6.801	<0.001	+
		July	2.745148	0.368197	7.456	<0.001	+
		June	2.692399	0.389583	6.911	<0.001	+
		September	1.234906	0.379653	3.253	<0.001	+
		Distance to shoreline	-0.003954	0.001830	-2.160	<0.05	-
	October – March	2009	0.55116	0.27372	2.014	<0.05	+
		January	-0.83909	0.43457	-1.931	<0.05	-
		November	-1.18577	0.38527	-3.078	<0.001	-
During construction	April - September	2012	-1.26376	0.23900	-5.288	<0.001	-
		August	1.38793	0.57735	2.404	<0.05	+
		July	2.00240	0.56132	3.567	<0.001	+
	October - March	2012	-0.482194	0.239980	-2.009	<0.05	-

Analysis of the Western Section for years pre and during construction complements data presented in previous chapters, however, to appropriately assess the success of created displacement habitat, analysis of use pre and post habitat creation was conducted.

When all months were combined and for the months of April - September, no differences in Gadwall numbers using the Western Section pre and post habitat creation were found. During October – March however, a significant increase was observed post habitat creation (Median pre-habitat = 0, post habitat = 1, Mann Whitney U_{892} , $p = <0.01$). This difference is largely attributable to Gadwall occupying a greater extent of the Western Section following habitat creation, illustrated using Kernel density estimation (KDE), (Figure 6.3).

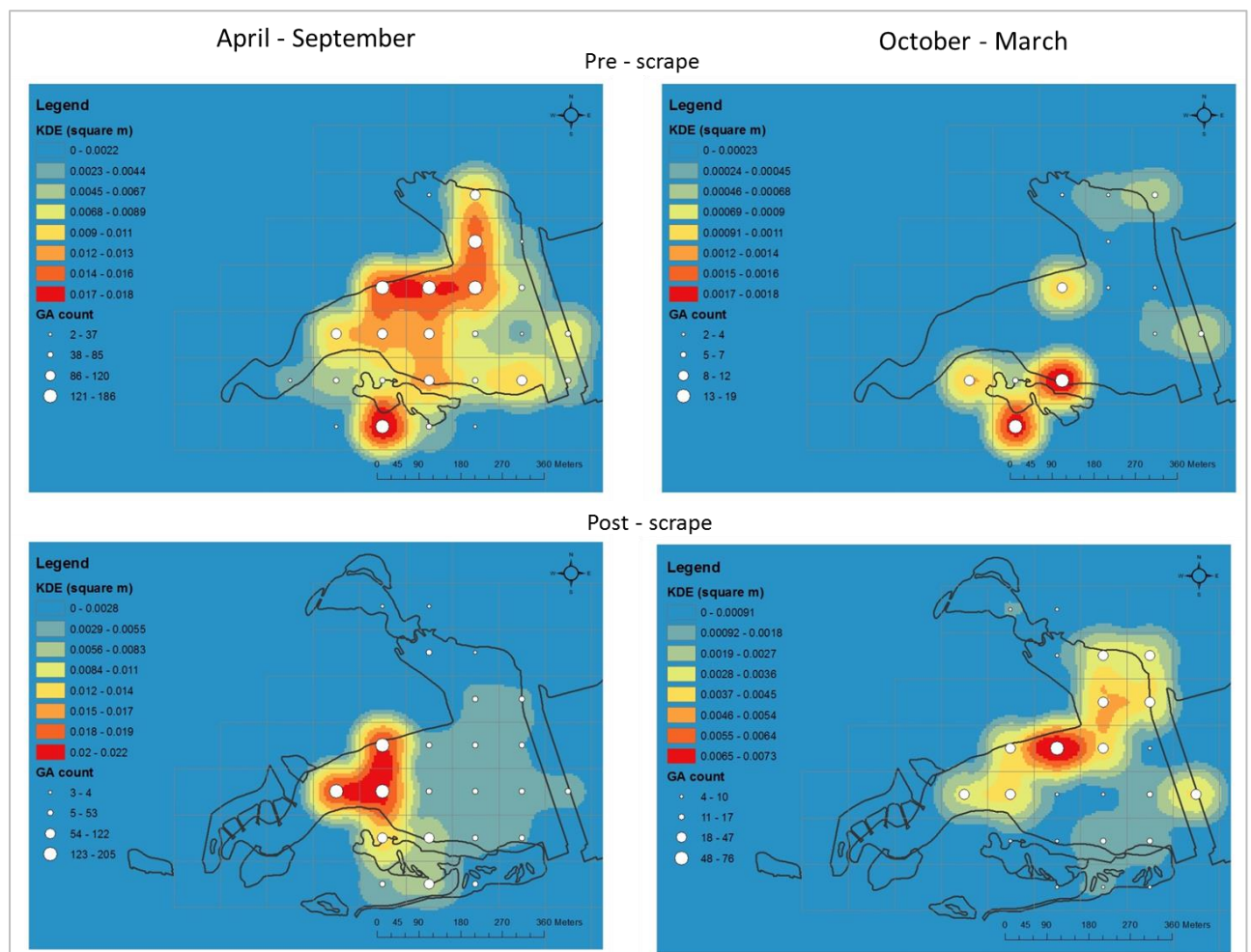


Figure 6.3: Kernel density estimation plots showing the density of Gadwall at the Western Section prior to and post habitat creation. Data are merged to represent the April – September and October – March periods and shown with the Refgrid layer. Density units represent the density of Gadwall per unit area (per m^2).

Results indicate that the creation of additional habitat provided overwintering Gadwall with additional habitat not previously available. This is supported by the number of Refgrid cells containing Gadwall increasing from 24 to 34 (Figure 6.4) following creation of the displacement habitat.

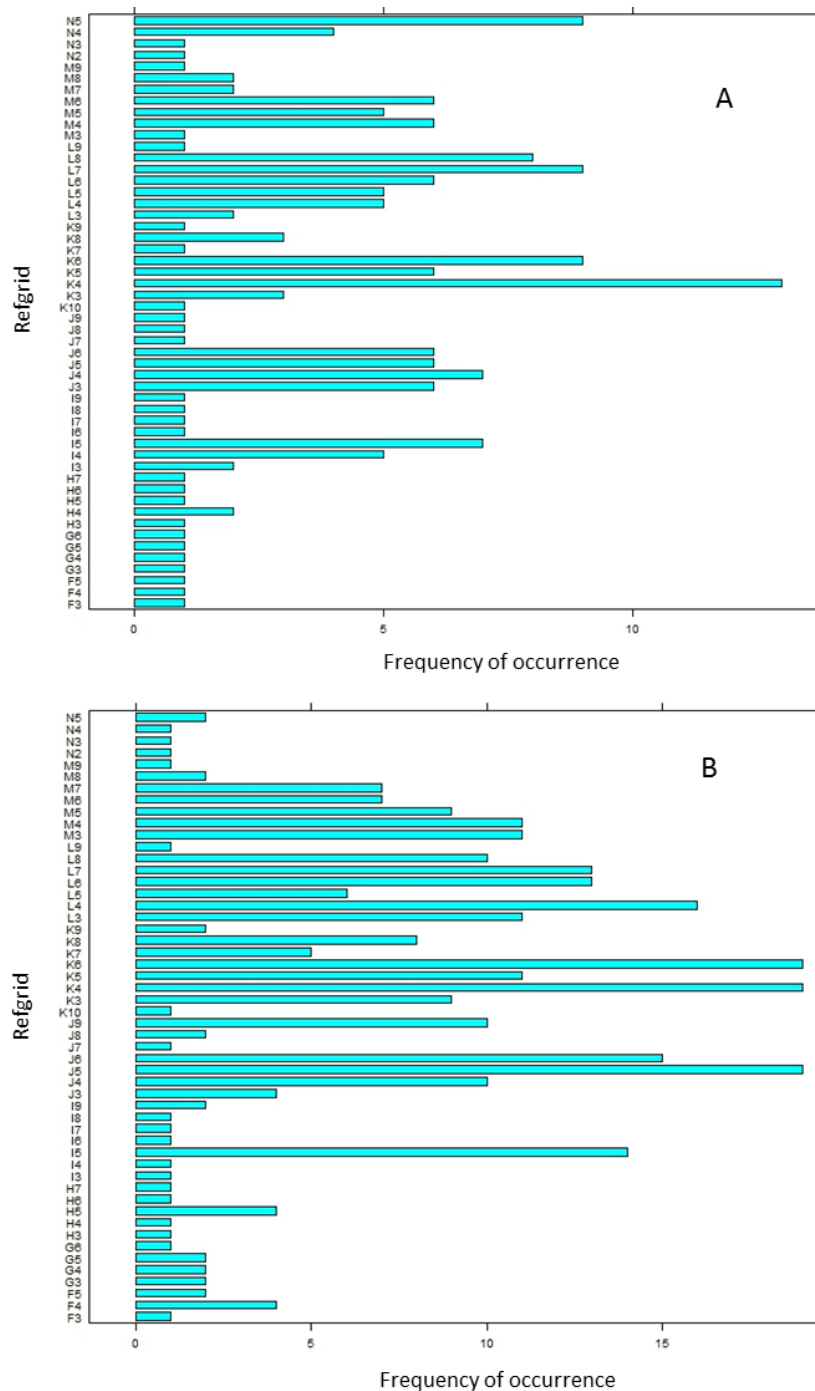


Figure 6.4: Frequency of occurrence of Gadwall within each Refgrid cell pre (A) and post scrape construction (B).

6.4.2 Shoveler

Comparisons in the distribution of Shoveler (Chapter 4) revealed a significant increase in numbers during construction for the spring/summer months compared to years pre-construction. A significant difference was also seen for the months of October – March where higher counts of Shoveler were observed for the Western Section during construction.

Further analysis shows that throughout the study years, use of the Western Section by Shoveler was consistently high for January and the summer months (Figure 6.5). During construction, particularly in December 2011 and October 2012, numbers in the Western Section increased significantly compared to the years prior with up to 80% of the total Abberton Reservoir population occupying the area.

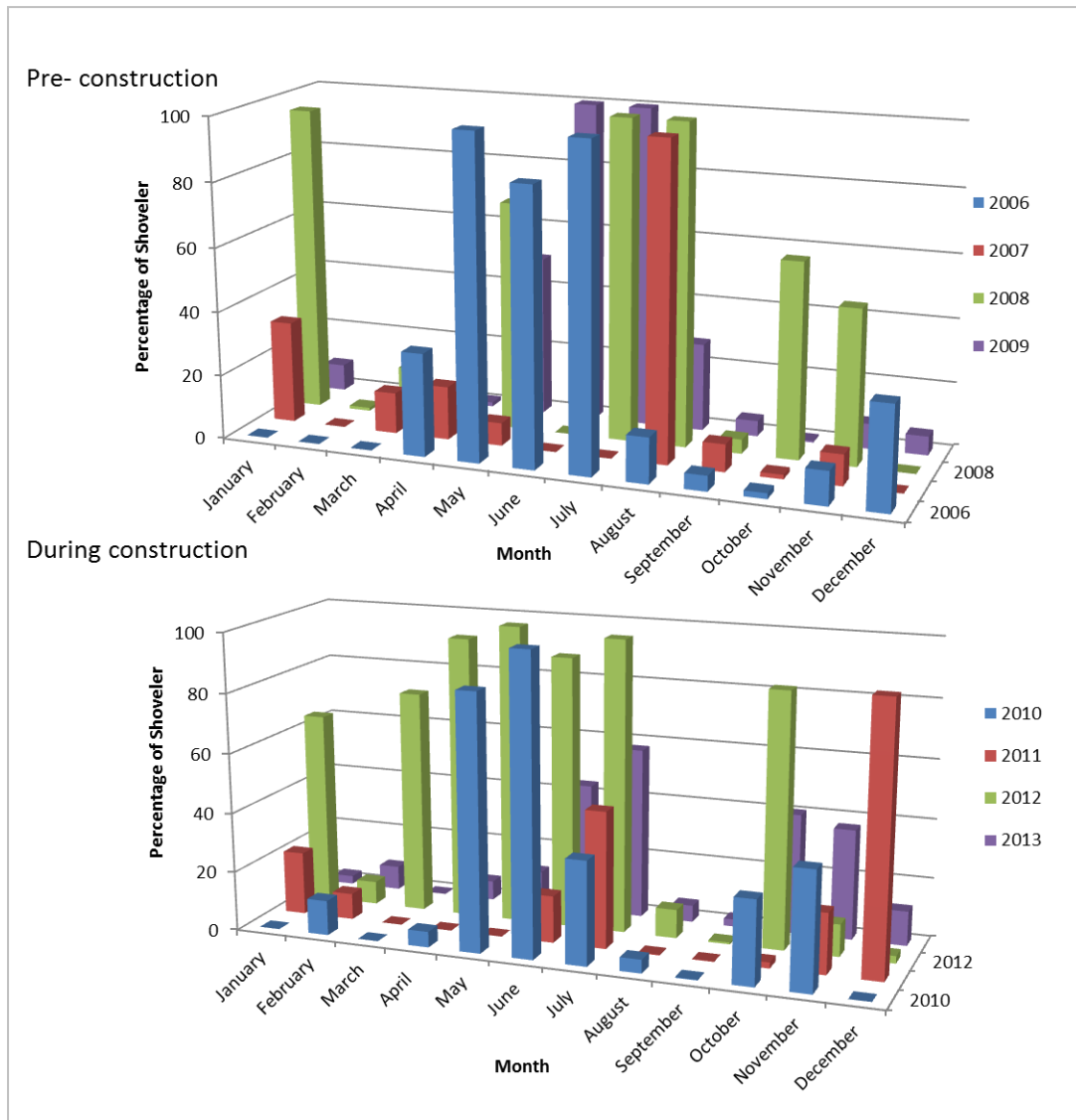


Figure 6.5: Percentage of the Abberton Reservoir Shoveler population present within the Western Section for years pre-construction (2006 - 2009) and during construction (2010 - 2013).

Results of GLM modelling, a summary of which is provided in Table 6.2 below, show a significant negative relationship in years pre-construction between numbers of Shoveler and macrophyte cover for both April – September and October – March periods. The effect of increasing distance to the shoreline is also negative and consistent with previous findings for these years which showed Shoveler to be preferentially located within 200m of the shoreline.

For the months of April – September during construction, the only positive predictor of numbers of Shoveler is the year 2013. With the exception of April, all months within this temporal period are

negative predictors; in the context of GLM modelling, this is interpreted that overall, and in comparison with other months, Shoveler counts at the Western Section during April were particularly high. Similarly, results for October to March show 2012 as the only positive predictor on numbers of Shoveler while the effect of February and March is negative i.e. counts were comparatively low during these months.

Table 6.2: Summary results of GLM for Shoveler pre-construction (2006 – 2009) and during construction (2010 – 2013). Analysis split between months spring/summer (April – September) and Autumn/winter (October – March).

Period	Time period	Variable	Estimate	Standard error	z value	p value	Relationship
Pre-construction	April - September	May	-1.02634	0.44464	-2.308	<0.05	-
		Macrophyte	-0.45934	0.19953	-2.302	<0.05	-
	October – March	2008	2.642307	0.253187	10.436	<0.001	+
		February	-3.939079	1.082415	-3.639	<0.001	-
		March	-1.173518	0.377614	-3.108	<0.001	-
		Distance to shoreline	-0.005403	0.001422	-3.800	<0.001	-
		Macrophyte	-0.302667	0.123932	-2.442	<0.01	-
During construction	April - September	2013	1.4785	0.3136	4.715	<0.001	+
		August	-0.8277	0.2644	-3.131	<0.01	-
		July	-0.9779	0.2662	-3.674	<0.001	-
		June	-1.4537	0.3222	-4.512	<0.001	-
		May	-1.6369	0.4284	-3.821	<0.001	-
		September	-1.4045	0.3394	-4.139	<0.001	-
	October - March	2012	1.12583	0.24056	4.680	<0.001	+
		February	-1.23298	0.37410	-3.296	<0.001	-
		March	-0.88040	0.31742	-2.774	<0.01	-

Despite differences in use of the Western Section pre and during construction and disparity in the mean and medians, no significant differences in number of Shoveler using the Western Section displacement habitat prior and post creation were found (Mann Whitney U test). Differences in the spatial distribution of Shoveler using the Western Section can however been seen when densities are plotted. Figure 6.6 shows that post displacement habitat/scrape creation, the highest densities of Shoveler were located on and around the shoreline and islands in habitat created south of the

main Western Section water body (SE phase 4). This preference is observed for both April – September and October – March periods.

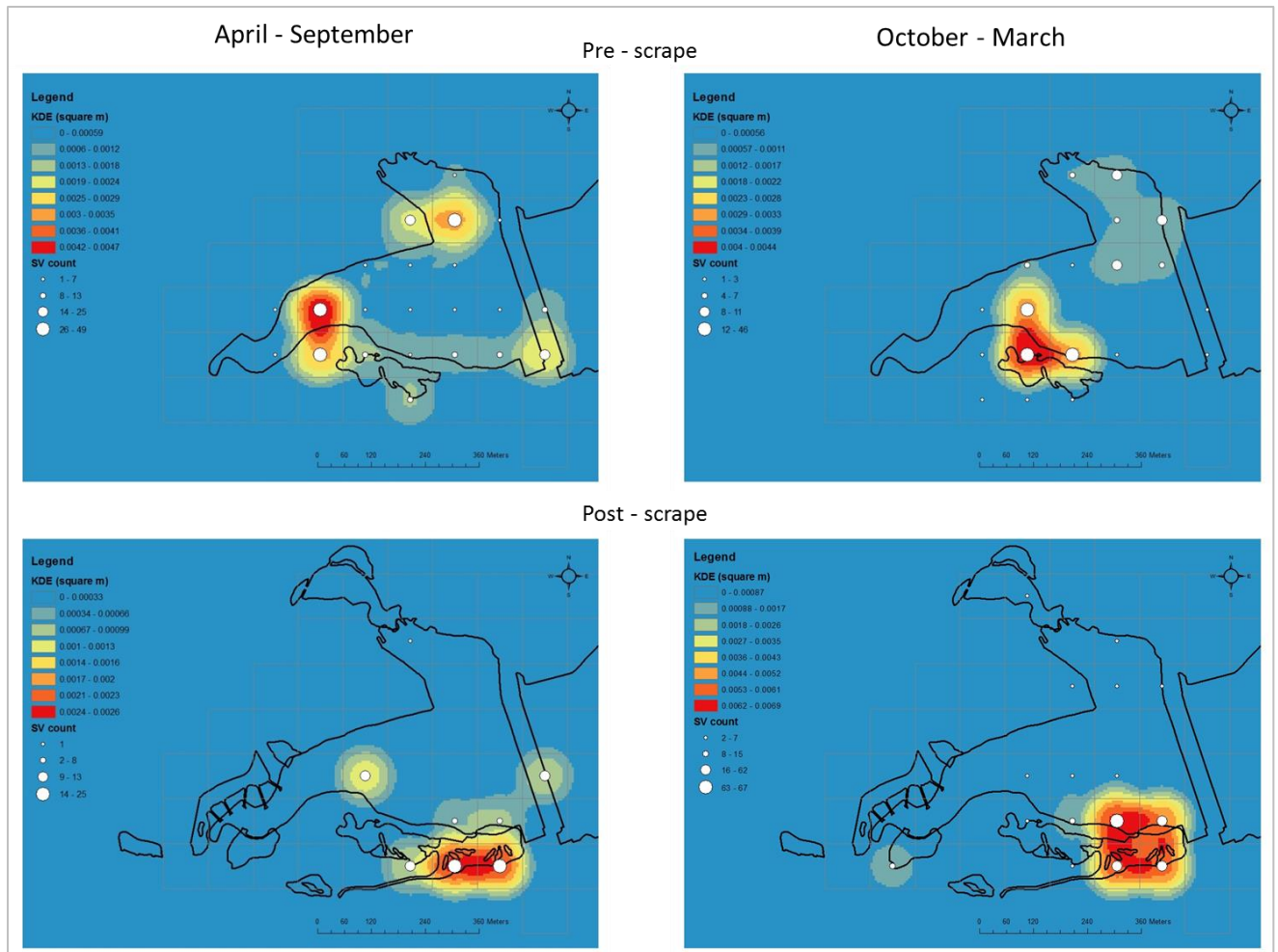


Figure 6.6: Kernel density estimation plots showing the density of Shoveler at the Western Section prior to and post habitat creation. Data are merged to represent the April – September and October – March periods and shown with the Refgrid layer. Density units represent the density of Shoveler per unit area (per m²).

Although Shoveler quickly utilised the newly created displacement habitat, and numbers were higher post – scrape creation, the number of Refgrid cells occupied during this time decreased from 31 pre-scape to 26 post-scape. This is shown in Figure 6.7 which also highlights that despite a lower total occupancy rate, the frequency of occurrence for individual Refgrid cells increased.

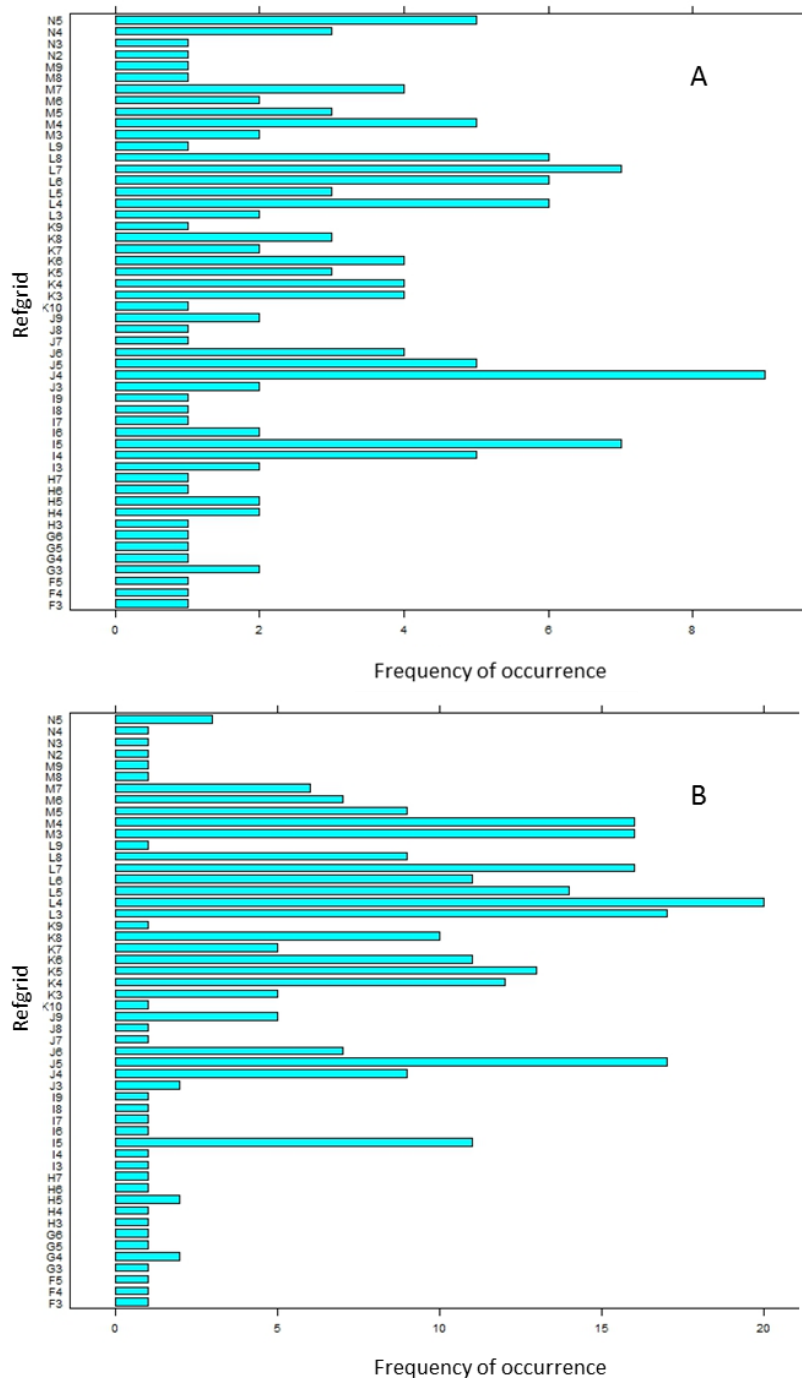


Figure 6.7: Frequency of occurrence of Shoveler within each Refgrid cell pre (A) and post scrape construction (B).

6.4.3 Teal

This study has shown that numbers of Teal significantly increased during construction; an observation made for both April – September and October – March periods with Teal favouring the Central Section during spring/summer and the Main Section in autumn/winter. Use of the Western

Section varied across all eight study years, with the area supporting the greatest percentage of the pre-construction Abberton population in July and August of 2008, although it was also important during August 2009. For the winter months, occupancy was fairly consistent between the months of January and April with up to 30% of Teal present at the Western Section (Figure 6.8). During years of construction, use of the Western Section was generally lower and more sporadic. However, over 90% of Abberton Teal were located in this section during March 2010 and May 2012.

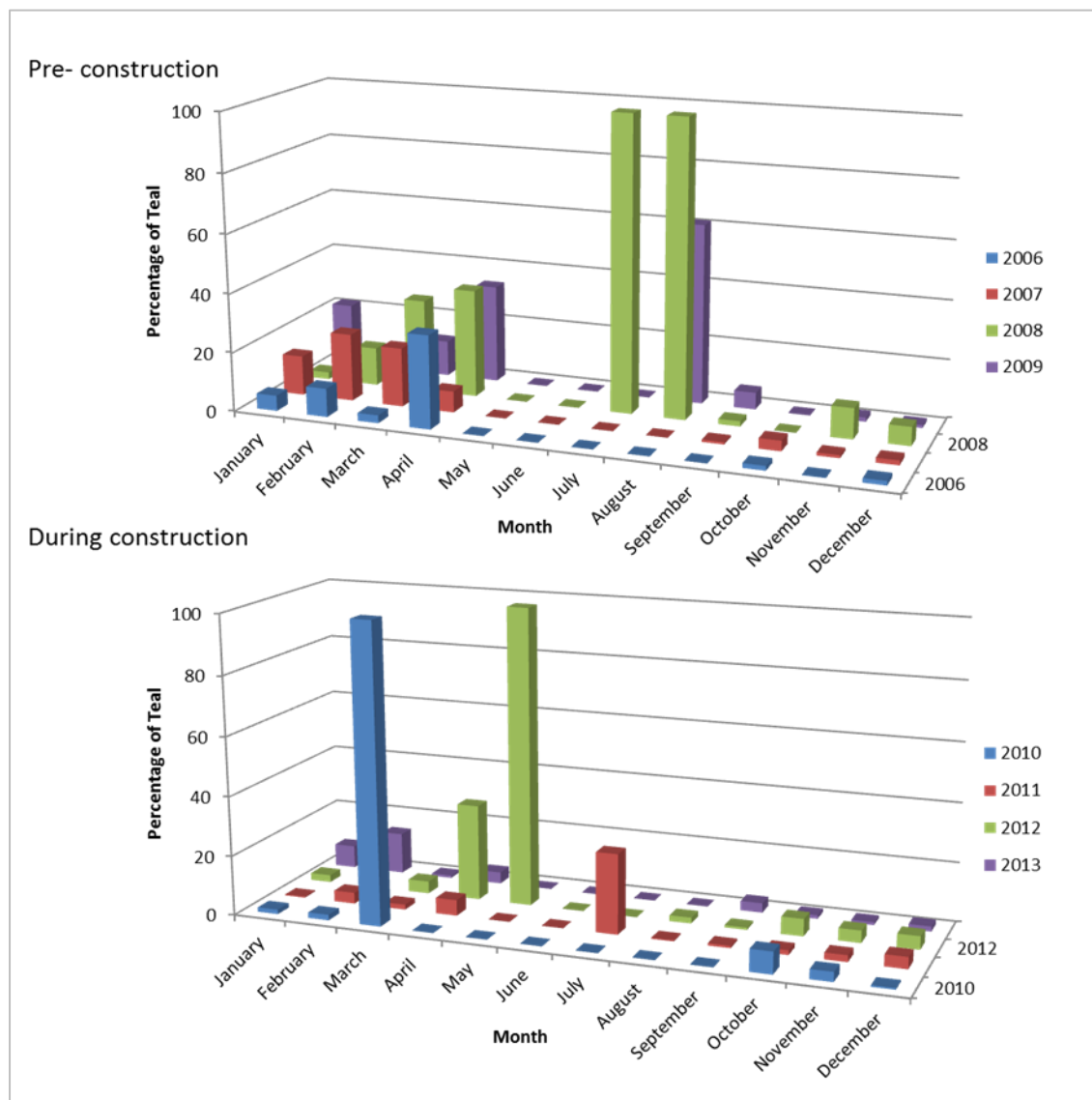


Figure 6.8: Percentage of the Abberton Reservoir Teal population present within the Western Section for years pre-construction (2006 - 2009) and during construction (2010 - 2013).

Due to a lower sample size (reflective of lower overall numbers) GLM analysis for years pre-construction included all months (January - December). The only significant variable for years 2006 – 2009 was month, for which the effect of November, December and January on numbers of Teal at the Western Section was positive (Table 6.3). Analysis during construction for the months of April - September revealed July and years 2012 and 2013 to have a significant positive effect and whilst this may seem in disagreement with Figure 6.8, it reflects higher counts as opposed to percentage of the population.

For the autumn/winter period, October was found to exert a positive influence on numbers of Teal whilst for March, a negative effect. The relationship between Teal and distance to the shoreline was significant with results supporting previous findings that at Abberton Reservoir, indicating that numbers of Teal decline with increasing distance from the shoreline.

Table 6.3: Summary results of GLM for Teal pre-construction (2006 – 2009) and during construction (2010 – 2013). Analysis split between spring/summer (April – September) and Autumn/winter (October – March).

Period	Time period	Variable	Estimate	Standard error	z value	p value	Relationship
Pre - construction	All months	December	1.70093	0.45224	3.761	<0.001	+
		January	1.32417	0.47069	2.813	<0.01	+
		November	1.25183	0.434338	2.882	<0.001	+
During construction	April - September	2012	0.7472	0.3152	2.371	<0.05	+
		2013	0.9416	0.3009	3.129	<0.001	+
		July	1.0747	0.4672	2.300	<0.05	+
	October - March	March	-0.902091	0.398516	-2.264	<0.001	-
		October	0.637207	0.283897	2.245	<0.05	+
		Distance to shoreline	-0.008878	0.003827	-2.320	<0.05	-

As reported in Chapter 4, numbers of Teal significantly increased at Abberton Reservoir during construction compared to years pre-construction, with no differences in use of the Western Section found. Additional analysis in order to specifically assess use of the displacement habitat shows that higher numbers of Teal used the area following displacement habitat creation. Significant differences were observed for combined monthly data i.e. pre/post creation (Median pre-habitat = 0, post habitat = 4.5, Mann Whitney $U_{955.5}$, $p = <0.00$), for the months April – September (Median

pre-habitat = 0 (mean = 1.37), post habitat = 0 (mean = 3.62), Mann Whitney $U_{1013.5}$, $p = <0.01$) and for October – March (Median pre-habitat = 0 (mean = 7.75), post habitat = 2 (mean = 38.58), Mann Whitney $U_{1036.5}$, $p = <0.05$). Similar to Gadwall, it is likely that Teal were able to quickly utilise the new habitat and Kernel density estimation plots combined with spatial distribution data show that the most southerly scrapes and surrounding areas were particularly attractive to this species (Figure 6.9).

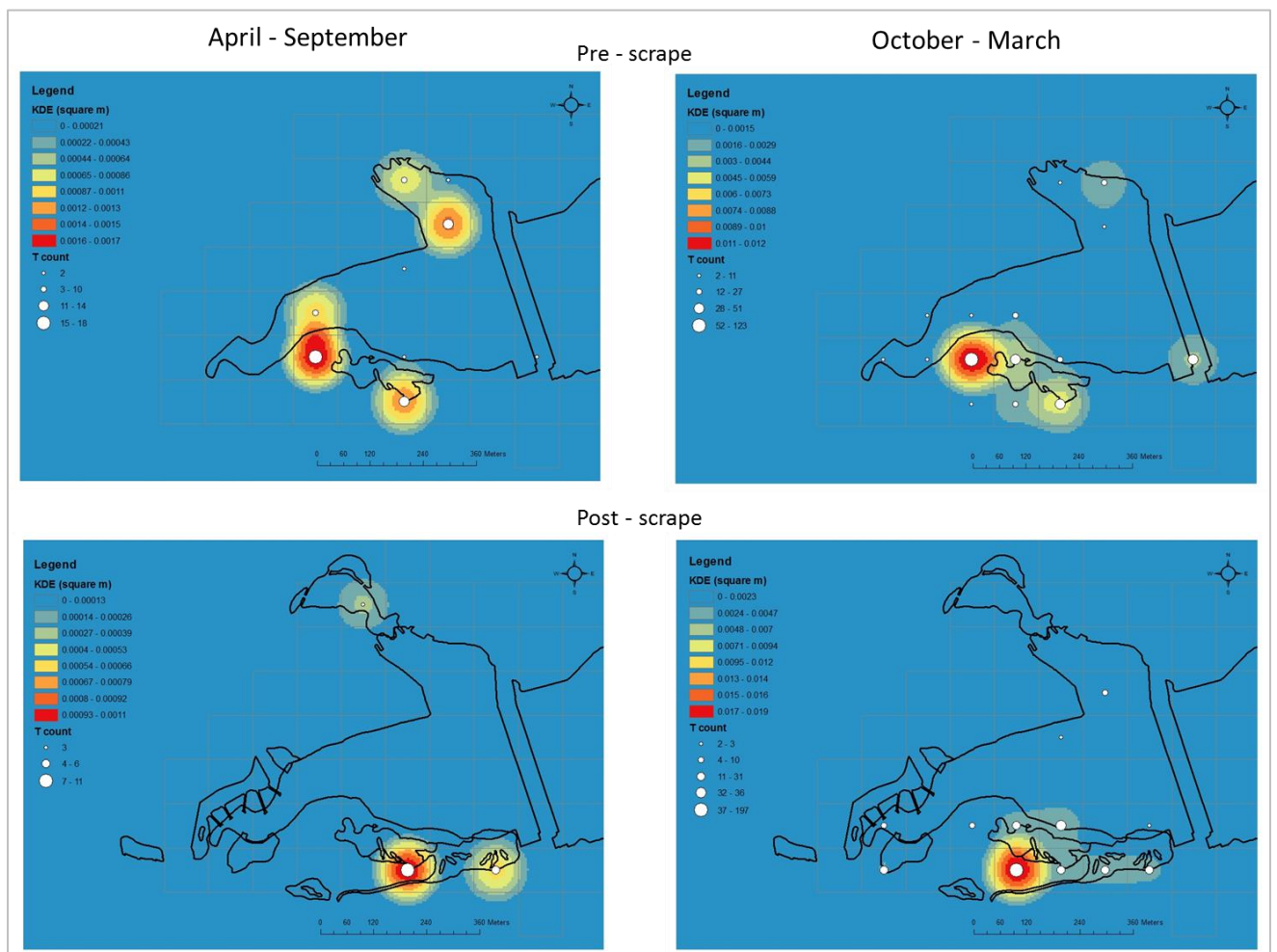


Figure 6.9: Kernel density estimation plots showing the density of Teal at the Western Section prior to and post habitat creation. Data are merged to represent the April – September and October – March periods and shown with the Refgrid layer. Density units represent the density of Teal per unit area (per m^2).

In addition to significantly higher counts, the number of $100m^2$ Refgrid cells occupied by Teal almost doubled from 16 pre-scape to 30, post-scape (Figure 6.10). The frequency of occupancy also substantially increased with the most frequently occupied cells prior to habitat creation being N4, located on the periphery of areas covered by the 2004 trial scrape and I4, a cell containing a

proportion of the concrete causeway embankment. Following habitat creation, L3 and M3 were the most occupied cells with the frequency increasing from 0 to 25 and 16 respectively. Both 100m² cells are located along southern extent of the Western Section.

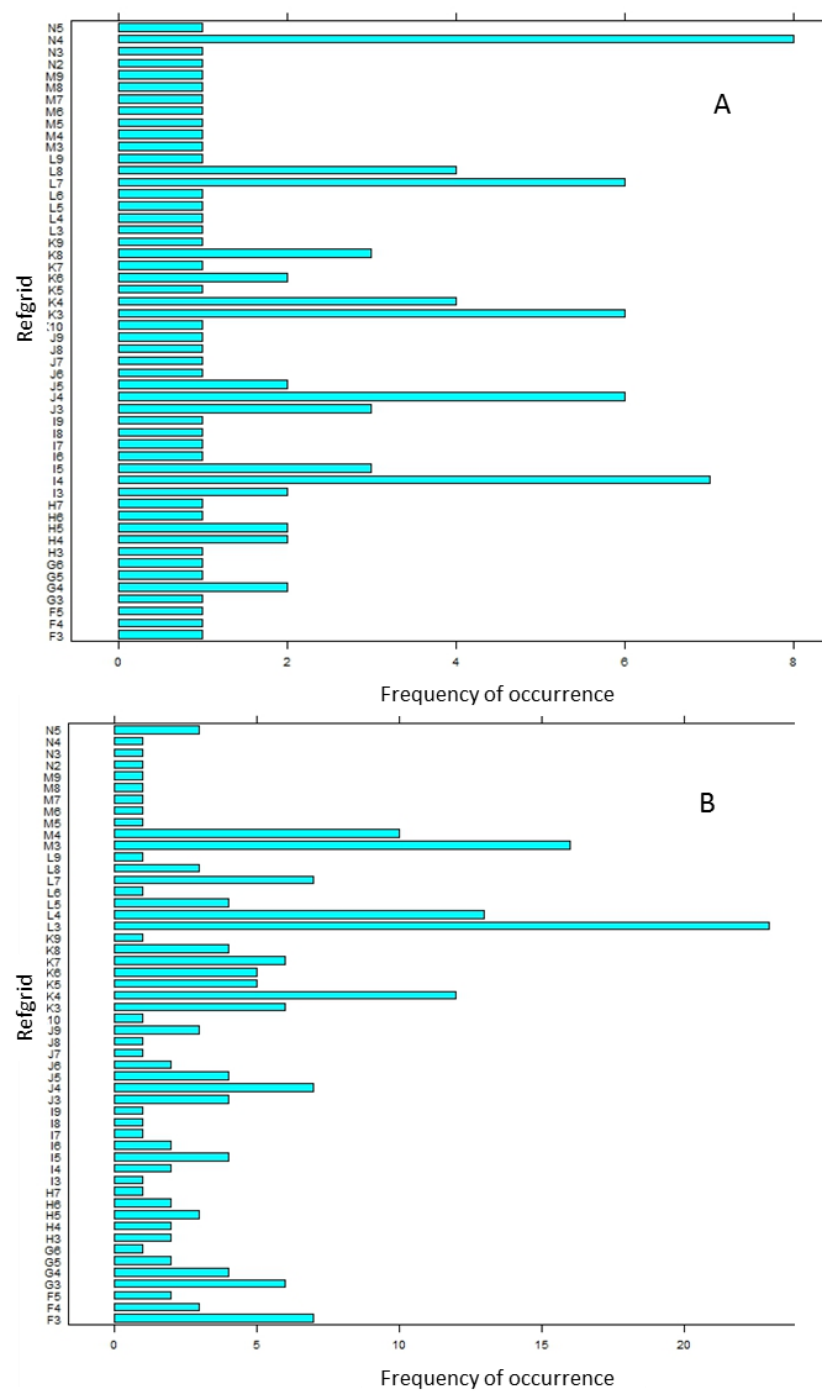


Figure 6.10: Frequency of occurrence of Teal within each Refgrid cell pre (A) and post scrape construction (B).

6.4.4 Wigeon

Numbers of Wigeon significantly increased at Abberton Reservoir during the active construction months (April – September); however a significant decrease was reported in both the Central and the Western Sections for October – March. The decline at the Western Section is clearly observed when the percentage of total Wigeon is plotted (Figure 6.11). In years pre-construction, 100% of the Abberton Reservoir Wigeon population were located at the Western Section between the months of May and August and up to 10% were present during the winter and early spring months. In comparison, during construction, only 60% of the Wigeon population were located on the Western Section for the spring/summer months with even less recorded for the autumn/winter months.

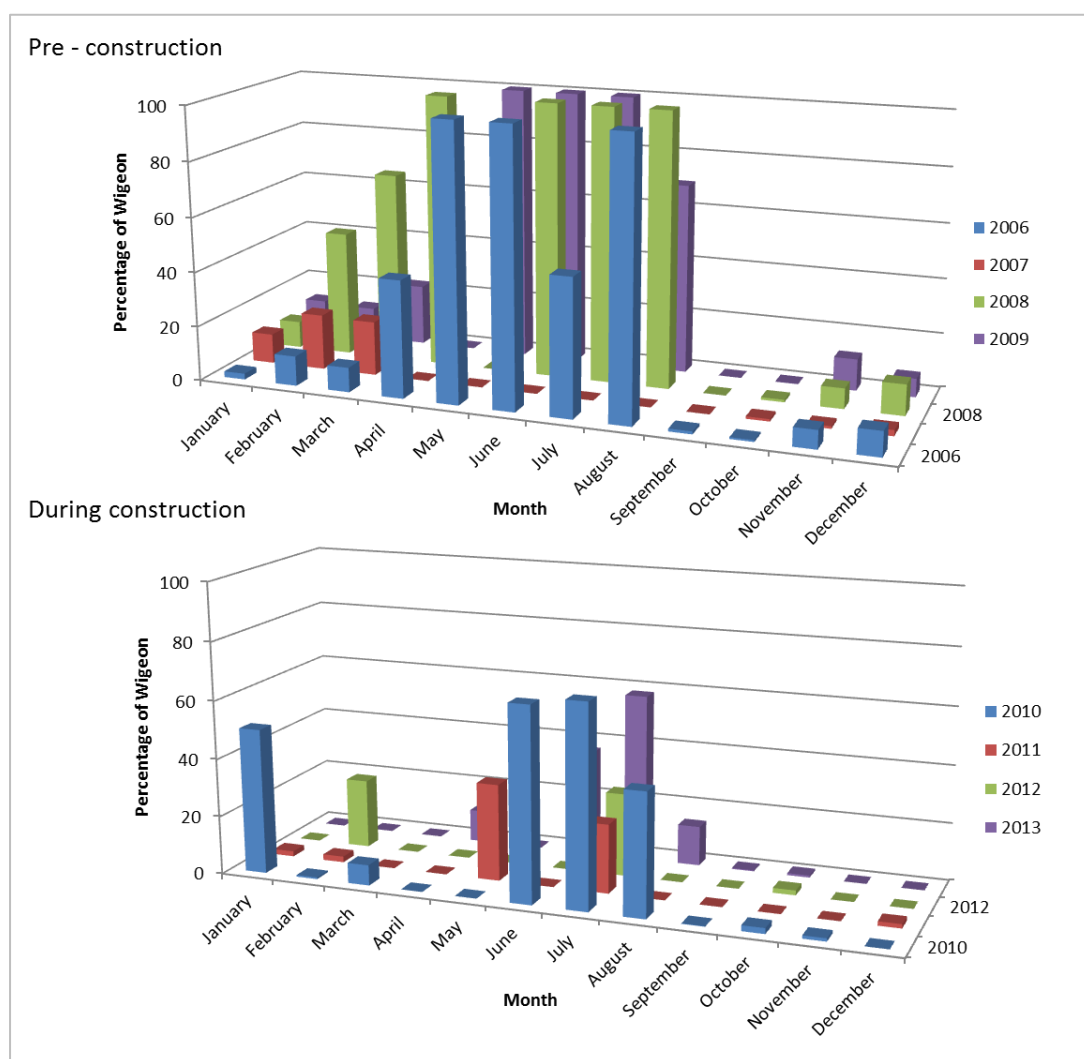


Figure 6.11: Percentage of the Abberton Reservoir Wigeon population present within the Western Section for years pre-construction (2006 - 2009) and during construction (2010 - 2013).

Whilst higher counts of Wigeon were reported for years prior to construction of the Abberton Scheme, the number of cells containing Wigeon (and therefore the sample size) was low across all eight years. Consequently, as with analysis of Teal pre-construction (see Table 6.3), GLM analysis for Wigeon used data for all 12 months of the year. A summary of results provided in Table 6.4.

Pre-construction, month was the only significant variable shown to influence numbers of Wigeon with May, June and August all exerting a negative influence. During construction, numbers were higher in 2012, demonstrated by the significant positive relationship observed for this variable. With the exception of July, months positively influencing numbers of Wigeon at the Western Section all fall within the October – March category. This reflects the annual count cycle at Abberton Reservoir for which numbers are higher during the over-wintering period and also demonstrates the disparity in monthly counts despite yearly totals remaining fairly constant.

Table 6.4: Summary results of GLM for Wigeon pre-construction (2006 – 2009) and during construction (2010 – 2013). Analysis combines all months due to low sample sizes.

Period	Time period	Variable	Estimate	Standard error	z value	p value	Relationship
Pre - construction	All months	August	-1.45121	0.541853	-2.679	<0.01	-
		June	-2.204762	0.701966	-3.141	<0.001	-
		May	-2.163414	0.861237	-2.512	<0.05	-
During construction	All months	2012	0.89192	0.25514	3.496	<0.001	+
		December	2.52088	0.87582	2.878	<0.001	+
		February	1.61462	0.81487	1.981	<0.05	+
		January	2.22816	0.84617	2.633	<0.01	+
		July	2.20183	0.79429	2.772	<0.01	+
		March	2.24310	0.92308	2.430	<0.05	+
		October	1.70342	0.80481	2.117	<0.05	+

Although differences between numbers of Wigeon at Abberton Reservoir pre and during construction are reported, analysis where Western Section count data were split between pre and post displacement habitat creation was non-significant (Mann-Whitney U). This suggests that the displacement habitat did not necessarily benefit Wigeon, or given the simultaneous increase for the

Main Section, was not as appealing. However, spatial distribution and Kernel density estimation (Figure 6.12) clearly show Wigeon were present at the scrape habitat with the highest densities shown for Refgrid cells containing edge and island habitat.

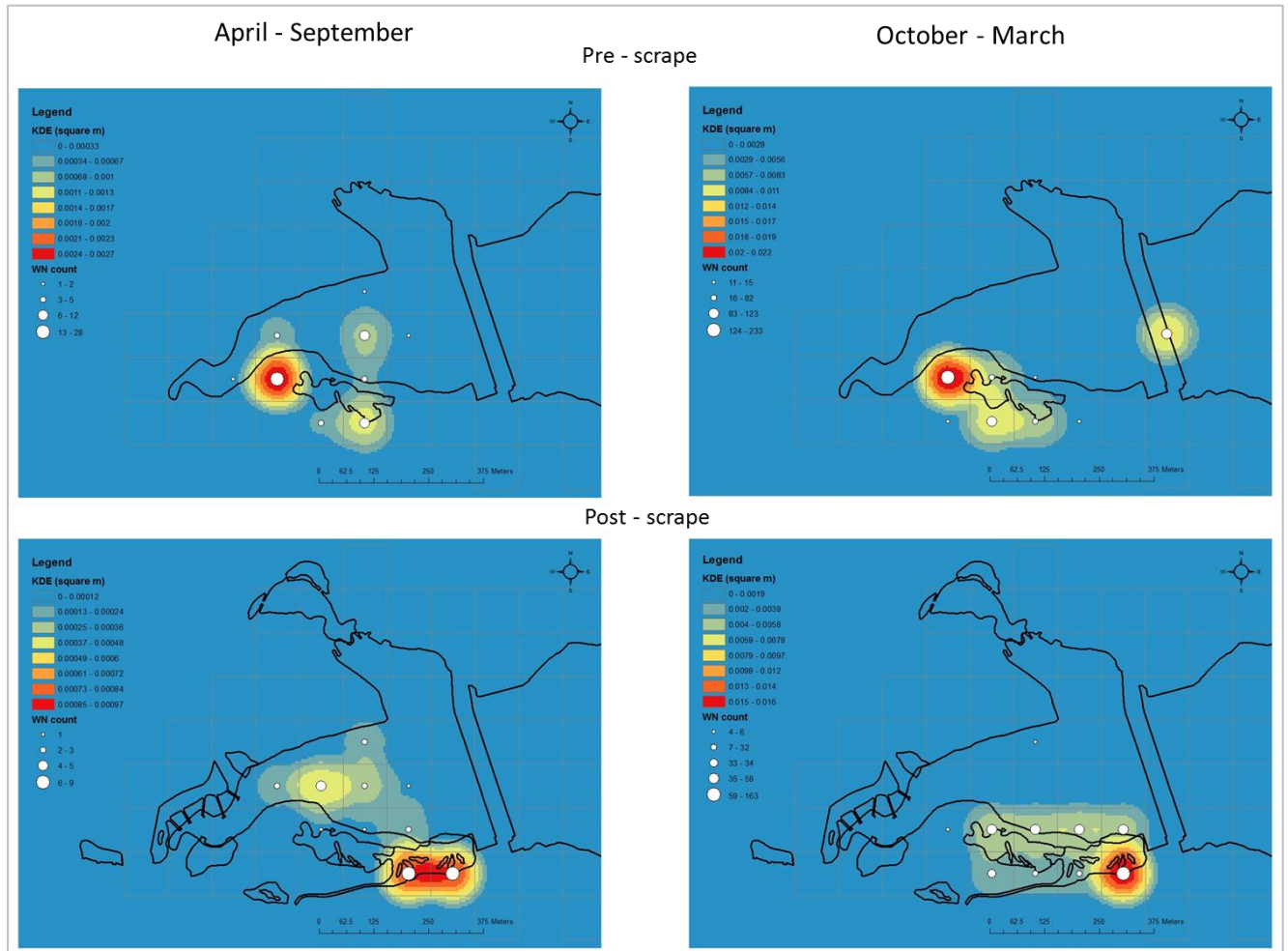


Figure 6.12: Kernel density estimation plots showing the density of Wigeon at the Western Section prior to and post habitat creation. Data are merged to represent the April – September and October – March periods and shown with the Refgrid layer. Density units represent the density of Wigeon per unit area (per m²).

Results presented above are further supported by frequency data shown in Figure 6.13. Wigeon used the newly created habitat and occupied 23 Refgrid cells post habitat creation compared to 13 pre-creation. However, unlike other species, the frequency occurrence for each cell decreased. This reflects the increase in spatial extent but general reduction in numbers occupying the Western Section with the change likely due to feeding opportunities.

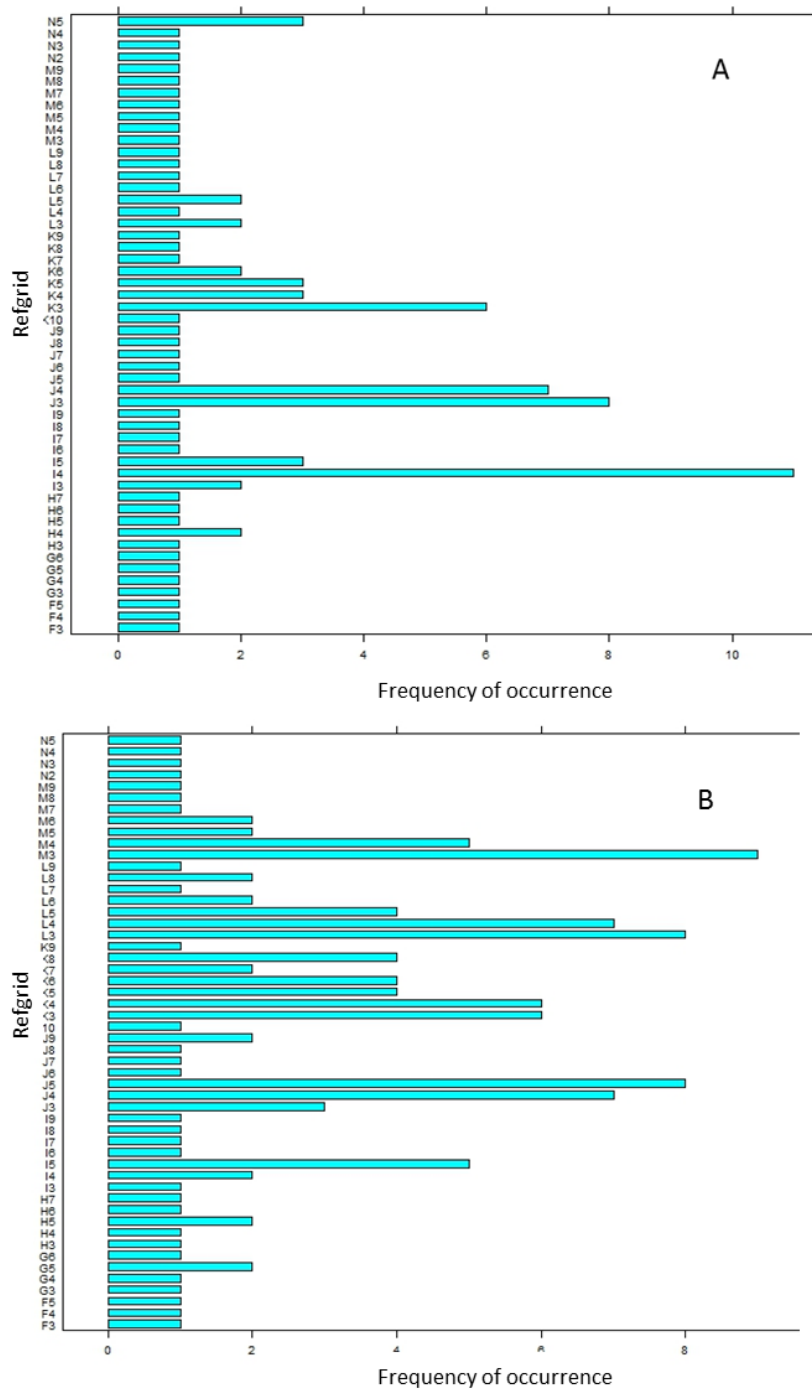


Figure 6.13: Frequency of occurrence of Wigeon within each Refgrid cell pre (A) and post scrape construction (B).

6.4.5 Coot

Use of the Western Section by Coot was consistent throughout the eight year study period with the highest percentage of the Abberton Reservoir population present during the months of May, June

and July (Figure 6.14). Prior analysis did not report any significant differences in numbers occupying the Western Section however the relative importance of the area declined during construction. This is likely due to the significant increase observed for the Main Section during 2010 – 2013.

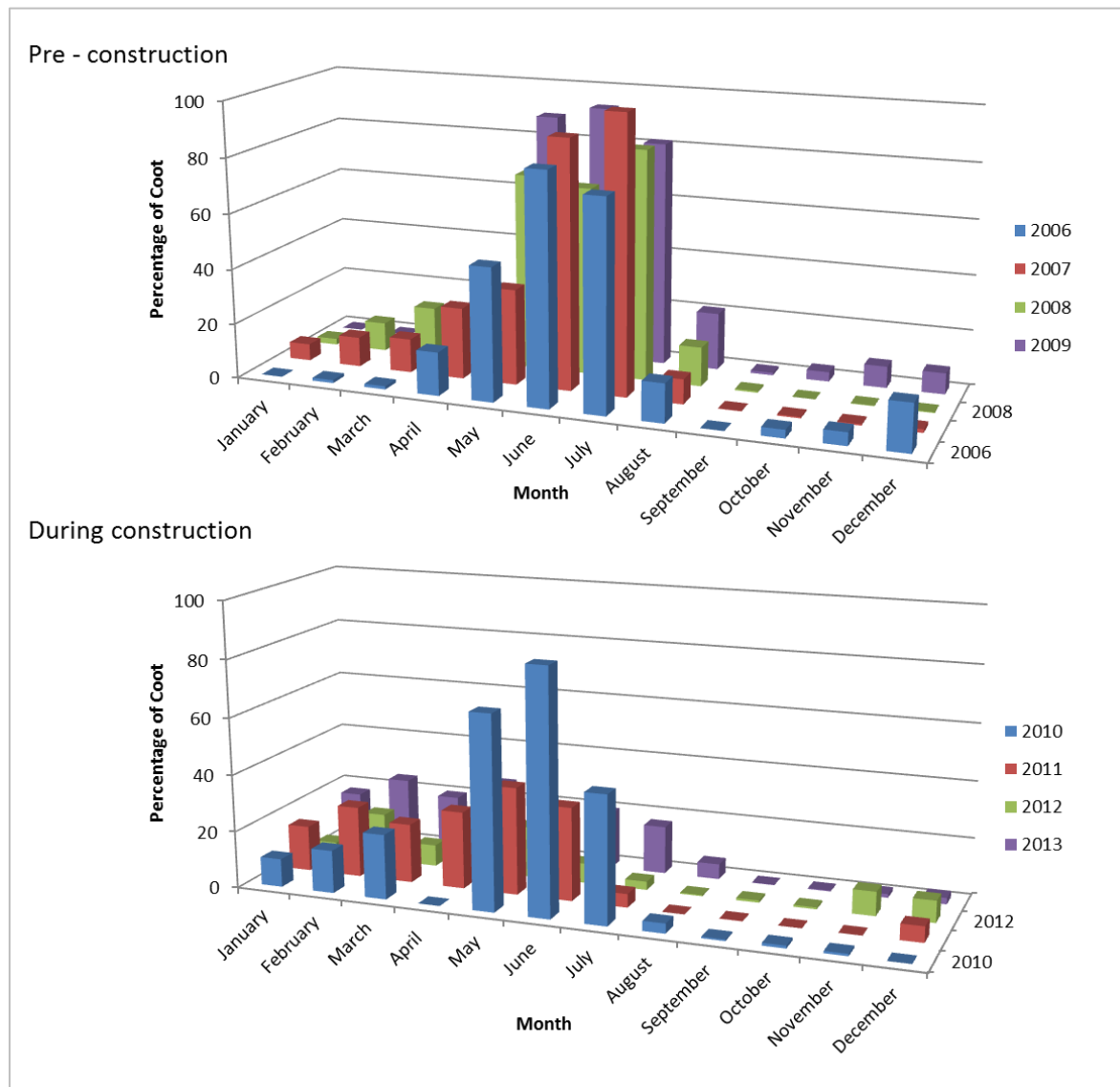


Figure 6.14: Percentage of the Abberton Reservoir Coot population present within the Western Section for years pre-construction (2006 - 2009) and during construction (2010 - 2013).

Statistical analysis (GLM) to further investigate factors affecting use of the Western Section by Coot show month and year to be of significant influence (Table 6.5). During April – September in years pre-construction, 2009 was a significant positive predictor as were the months of June, July and August. This result combined with the finding that the Western Section supported on average 80% of

the Coot population (Figure 6.14 above) during June and July demonstrates the importance of this section to this species at this time. For October – March, covariates exerting a positive effect on numbers of Coot are 2007, 2008 and the month of October. Those associated with a negative effect are January, February and March.

During construction, 2013 was shown to negatively affect Coot at the Western section for both April – September and October – March periods. The lack of this species at Abberton Reservoir during 2013 was also reported in the previous chapter where Hurdle model analysis associated it with the prediction of a zero count outcome. Jointly this suggests the final year of construction was particularly poor for Abberton Reservoir Coot. Similar to years pre-construction, June and July are shown to be positively associated with numbers of Coot during construction; further substantiating the preference and importance of the Western Section for this species during the summer months.

Table 6.5: Summary results of GLM for Coot pre-construction (2006 – 2009) and during construction (2010 – 2013). Analysis split between months spring/summer (April – September) and Autumn/winter (October – March).

Period	Time period	Variable	Estimate	Standard error	z value	p value	Relationship
Pre - construction	April - September	2009	0.7297	0.1155	6.319	<0.001	+
		August	1.9138	0.1822	10.501	<0.001	+
		July	2.6386	0.1781	14.813	<0.001	+
		June	1.2631	0.1811	6.974	<0.001	+
	October – March	2007	0.7976	0.1951	4.088	<0.001	+
		2008	0.6989	0.2016	3.465	<0.001	+
		February	-0.8330	0.2118	-3.934	<0.001	-
		January	-0.6695	0.2786	-2.403	<0.05	-
		March	-1.0032	0.1958	-5.124	<0.001	-
		October	0.4501	0.1751	2.571	<0.01	+
During construction	April - September	2012	-1.4092	0.1976	-7.132	<0.001	-
		2013	-1.4092	0.1638	-5.529	<0.001	-
		August	0.8945	0.2598	3.443	<0.001	+
		July	1.4429	0.2153	6.701	<0.001	+
		June	0.5356	0.2086	2.568	<0.01	+
	October - March	2013	-0.49174	0.14662	-3.354	<0.001	-
		February	0.64961	0.17270	3.762	<0.001	+
		January	0.38089	0.18956	2.009	<0.05	+

To investigate the effect of additional habitat creation (created for the purpose of displacement habitat provision) on numbers of Coot at the Western Section, Mann-Whitney U tests were used to assess differences in numbers pre and post habitat creation. Results show that the creation of additional scrapes and habitat at the Western Section had significant benefits for this species.

Results show that overall, numbers of Coot were significantly higher post habitat creation (Median pre-habitat = 4, post habitat = 20, Mann Whitney U_{1005} , $p = <0.05$) with the difference observed for both April – September (Median pre-habitat = 0, post habitat = 10, Mann Whitney U_{1009} , $p = <0.05$) and October – March (Median pre-habitat = 1, post habitat = 8.5, Mann Whitney U_{1001} , $p = <0.05$) periods.

Increased use of the Western Section by Coot following the creation of additional scrape habitat is visualised utilising Kernel density estimation and frequency occurrence plots. Figure 6.15 shows the spatial distribution and resulting densities of Coot between the four temporal periods and Figure 6.16, the frequency of occurrence per available 100m² Refgrid cell. Post scrape creation, the number of Refgrid cells containing Coot increased to 37 from a total of 29 pre-construction. This difference is due to this species utilising the additional scrapes to the south and the most westerly arm of the existing Western Section; a likely response to the maturing reedbed habitat bordering this area. Interestingly, despite Coot dispersing to areas of new habitat, the highest densities were observed for the main and original body of water which may be due to the presence of large aggregations of this flocking species.

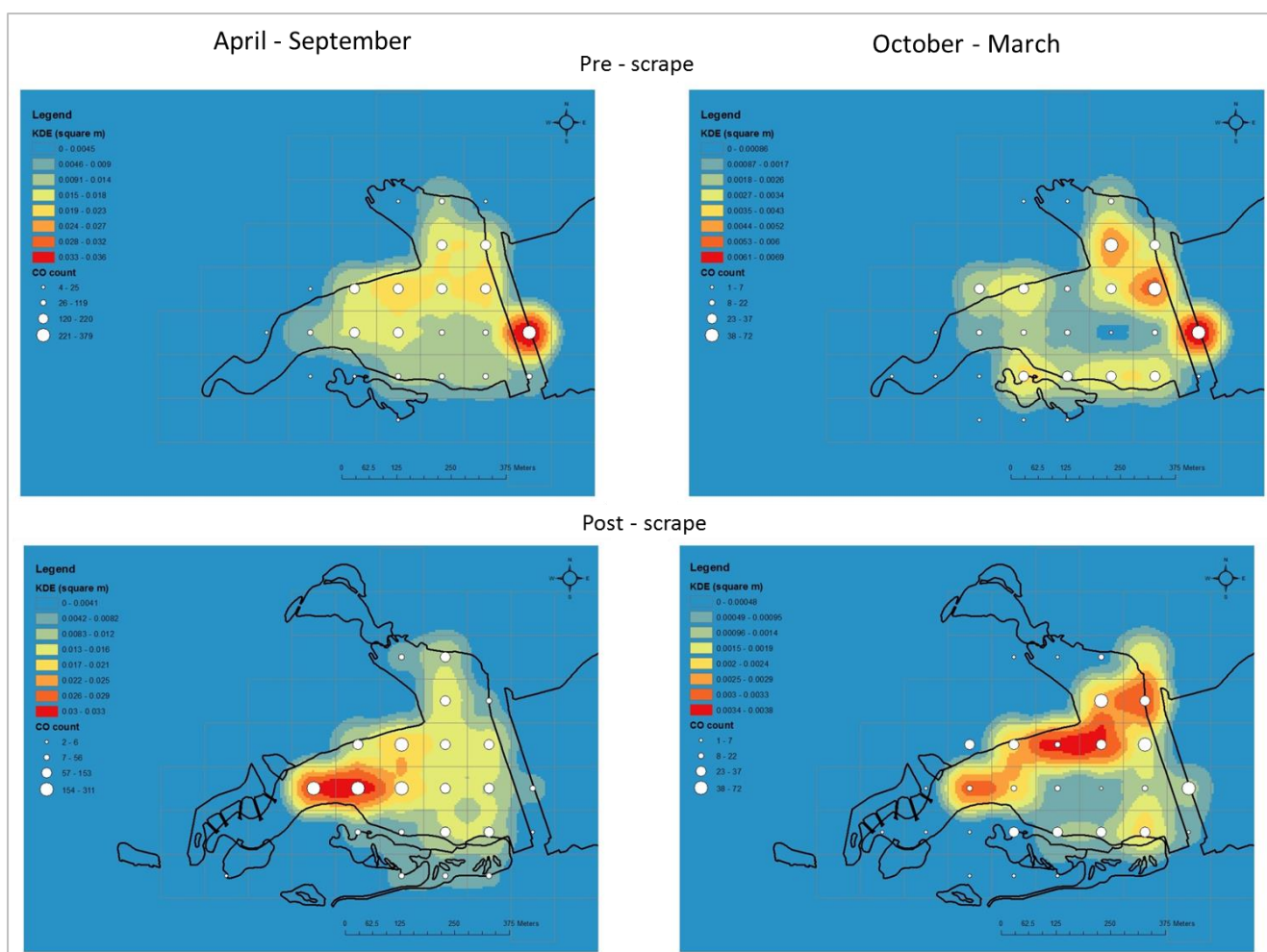


Figure 6.15: Kernel density estimation plots showing the density of Coot at the Western Section prior to and post habitat creation. Data are merged to represent the April – September and October – March periods and shown with the Refgrid layer. Density units represent the density of Coot per unit area (per m^2).

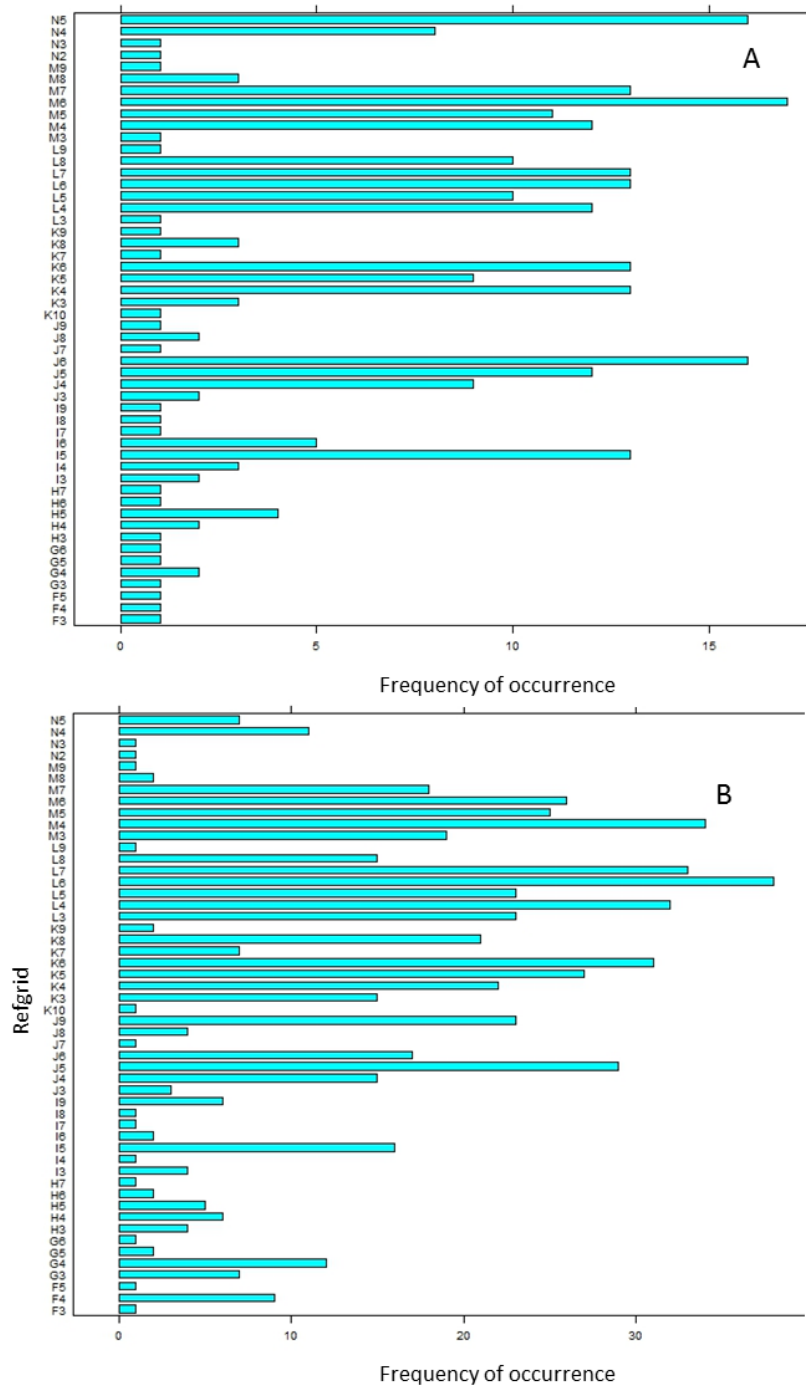


Figure 6.16: Frequency of occurrence of Coot within each Refgrid cell pre (A) and post scrape construction (B).

5.4.6 Tufted Duck

Analysis has shown that for the combined months of October – March, numbers of Tufted Duck at Abberton Reservoir significantly declined during construction. Use of the Western Section, in terms of percentage of the population occupying the area also decreased (Figure 6.17). With the exception

of 2010 and the month of June, the Western Section supported less than 40% of the Abberton Reservoir Tufted Duck population in years during construction. In comparison, between 60 and 100% of this species were present in January and February 2006 and between the months of June and August for the majority of pre-construction years.

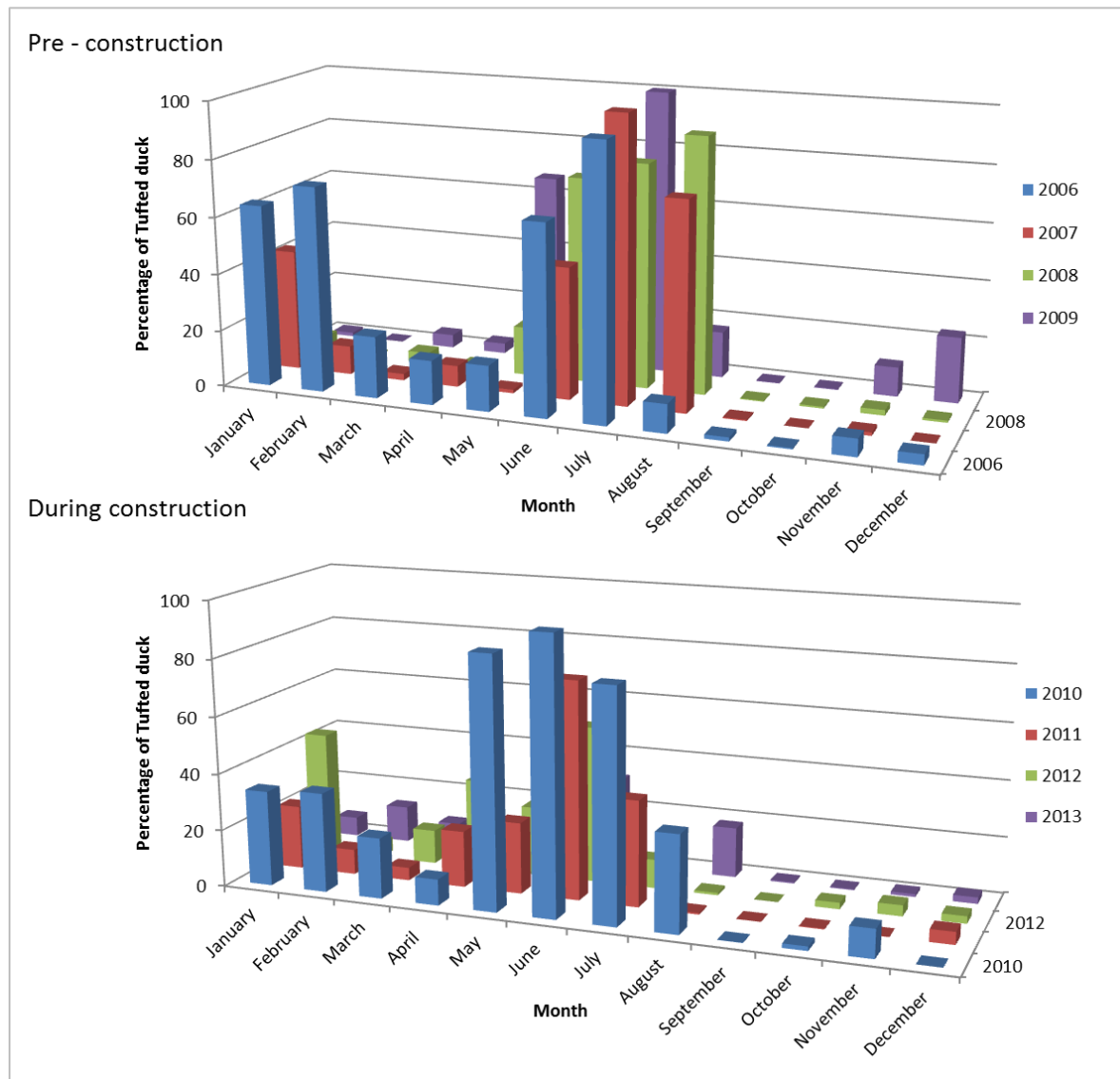


Figure 6.17: Percentage of the Abberton Reservoir Tufted Duck population present within the Western Section for years pre-construction (2006 - 2009) and during construction (2010 - 2013).

GLM analysis, a summary of which is provided in Table 6.6, shows that, year and month are the only significant covariates affecting numbers of Tufted Duck at the Western Section. For the months April – September in years pre-construction, 2009, May, June and September are negative predictors

whereas the effect of August is positive. August is also the only significant positive monthly predictor during construction and coincides with the arrival of migrating waterfowl to the site.

Although aggregations of Tufted Duck at Abberton Reservoir typically increase during the autumn/winter months, comparatively the Western Section contributes little, and in years pre-construction, October along with 2007 and 2008 exert a negative influence on numbers of this species. The relationship for October during construction is also negative, whereas throughout the years, the effect of January and February is positive.

Table 6.6: Summary results of GLM for Tufted Duck pre-construction (2006 – 2009) and during construction (2010 – 2013). Analysis split between months spring/summer (April – September) and Autumn/winter (October – March).

Period	Time period	Variable	Estimate	Standard error	z value	p value	Relationship
Pre - construction	April - September	2009	-0.6278	0.1668	-3.764	<0.001	-
		August	0.6522	0.1477	4.508	<0.001	+
		June	-0.7320	0.2330	-3.142	<0.01	-
		May	-0.5426	0.2721	-1.994	<0.05	-
		September	-1.1666	0.2496	-4.673	<0.001	-
	October – March	2007	-1.1478	0.3037	-3.779	<0.001	-
		2008	-0.9402	0.2577	-3.648	<0.001	-
		February	0.9469	0.3839	2.466	<0.01	+
		January	1.4560	0.3347	4.351	<0.001	+
		October	-0.9604	0.4152	-2.313	<0.05	-
During construction	April - September	2012	0.42794	0.20648	2.073	<0.05	+
		August	1.18859	0.23718	5.011	<0.001	+
		May	-1.03942	0.25720	-4.041	<0.001	-
	October - March	2011	-0.6062	0.2303	-2.632	<0.01	-
		2013	-0.4797	0.2191	-2.189	<0.05	-
		February	0.8433	0.2684	3.142	<0.001	+
		January	1.2543	0.2599	4.826	<0.001	+
		March	0.5325	0.2652	2.008	<0.05	+
		October	-0.6094	0.2981	-2.044	<0.05	-

When numbers of Tufted Duck at the Western Section were assessed in relation to creation of displacement habitat, no significant differences were found. Nevertheless, distributional data highlights dissimilarities in the density of this species for year's pre and post habitat (scrape) creation. Figure 6.18 shows the calculated Kernel density estimation along with the count data

within each corresponding 100m² Refgrid cells. Data show that counts and the associated densities were higher for years prior to habitat creation, particularly for the months of April – September.

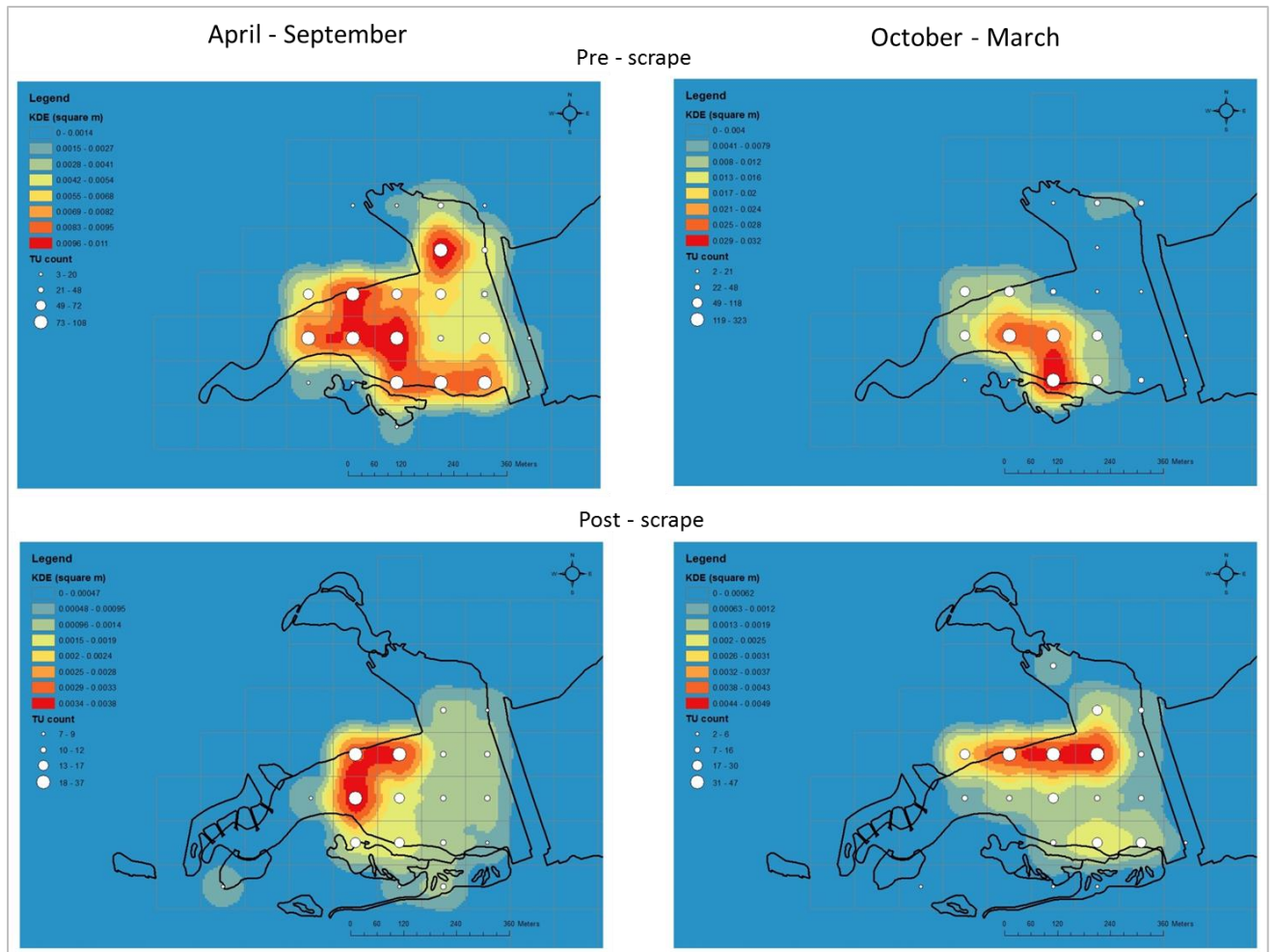


Figure 6.18: Kernel density estimation plots showing the density of Tufted Duck at the Western Section prior to and post habitat creation. Data are merged to represent the April – September and October – March periods and shown with the Refgrid layer. Density units represent the density of Tufted Duck per unit area (per m²).

Based on information presented above, the success of displacement habitat created for Tufted Duck appears limited however; the additional habitat did enable this species to occupy a greater extent of the Western Section. Figure 6.19 shows the frequency with which Tufted Duck occupied each 100m² Refgrid cell pre and post habitat creation. Prior to habitat creation a total of 24 Refgrid cells were occupied and this increased to 31 following enlargement of the area. Furthermore, the frequency of occurrence doubled.

Despite the area utilised by this species following habitat creation increasing in spatial extent, Tufted Duck demonstrate a consistent preference for the K, L and M cells. These are all located within the main and original body of the Western Section and are those containing the deepest water.

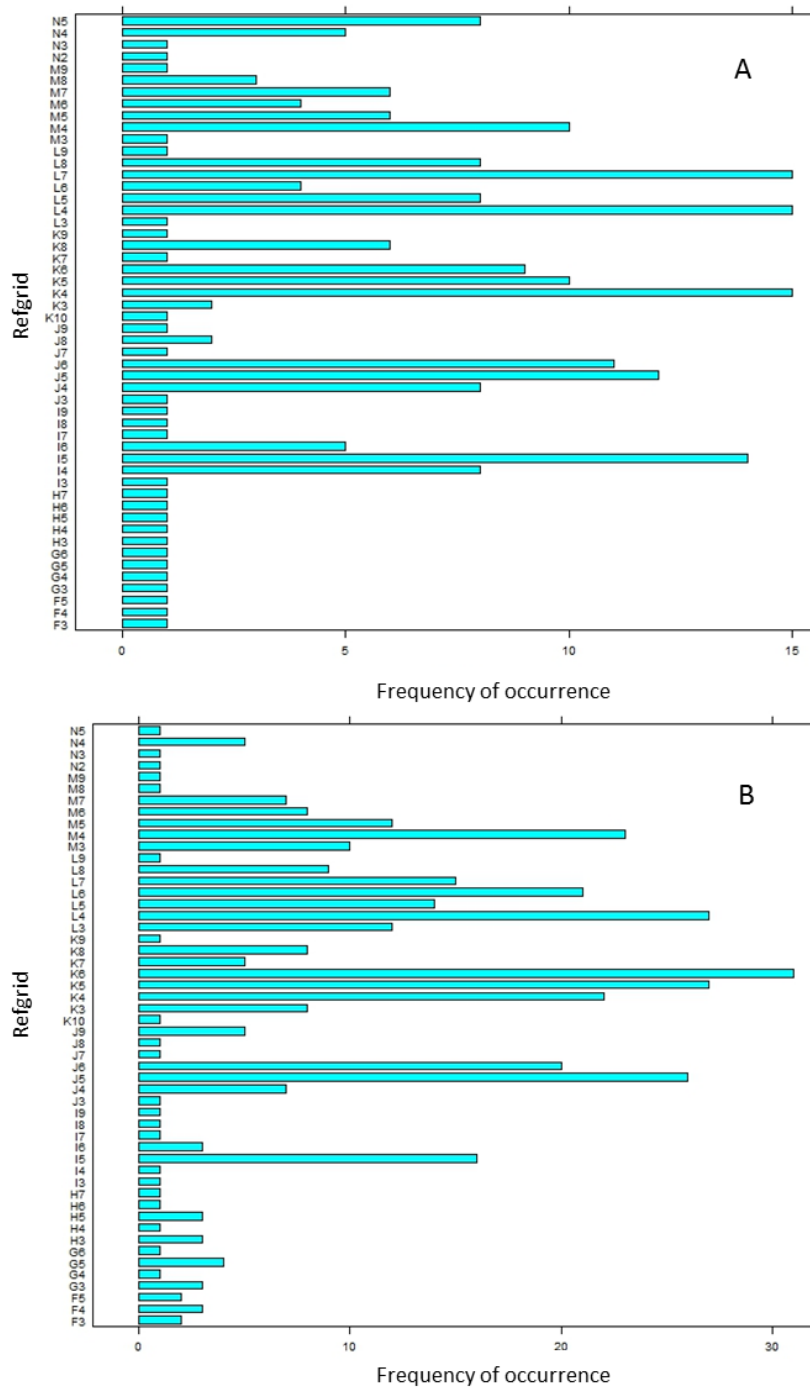


Figure 6.18: Frequency of occurrence of Tufted Duck within each Refgrid cell pre (A) and post scrape construction (B).

6.4.7 Pochard

Previous analysis carried out as part of this study did not find any significant differences in numbers of Pochard using the Western Section during construction compared with years pre-construction.

Use and spatial distribution of this section throughout the study years was consistent with the smaller Western Section supporting the majority of the Abberton Reservoir Pochard population between December and February and May through to July (Figure 6.19).

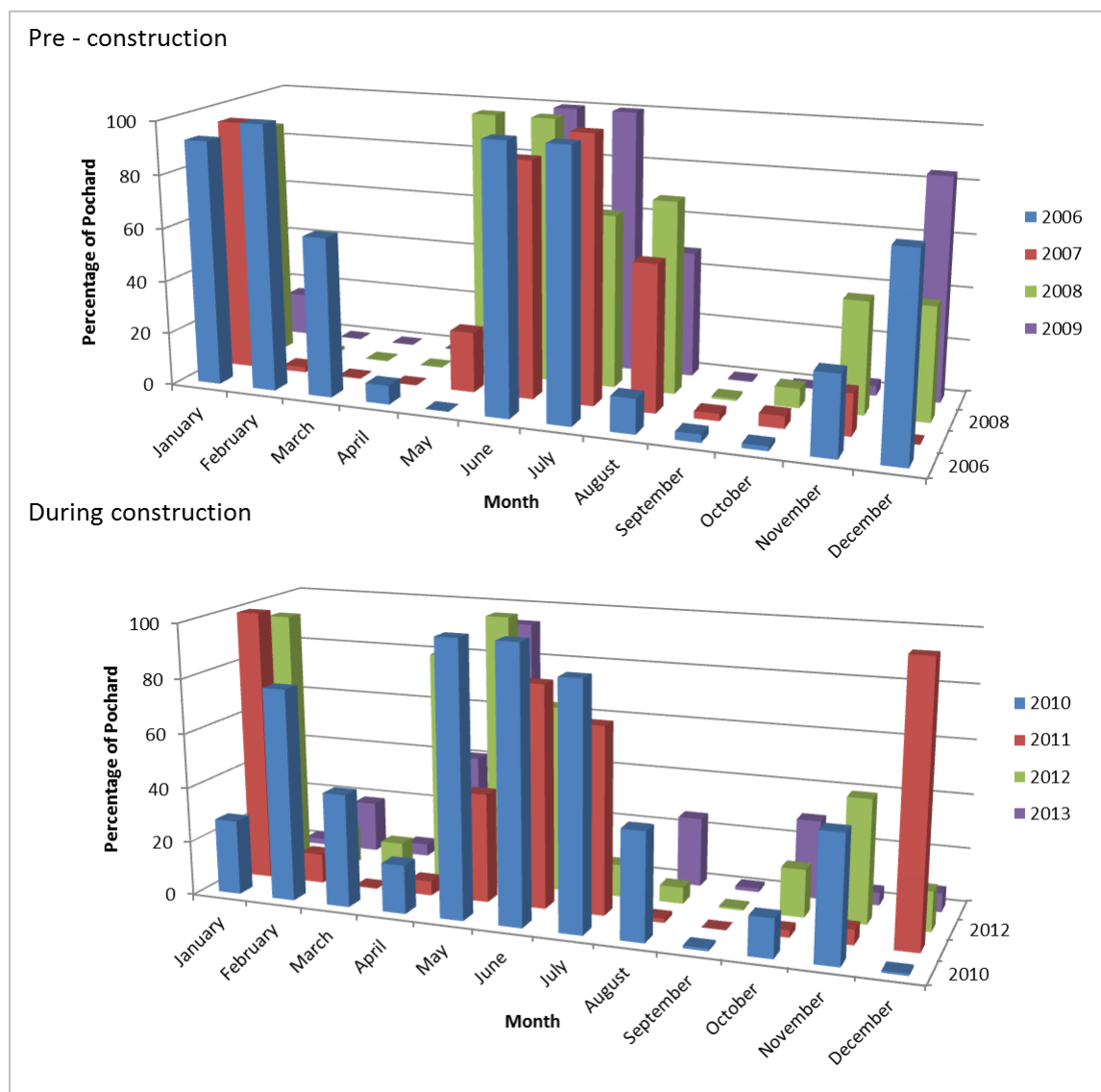


Figure 6.19: Percentage of the Abberton Reservoir Pochard population present within the Western Section for years pre-construction (2006 - 2009) and during construction (2010 - 2013).

A summary of GLM model outputs for Pochard is provided in Table 6.7. Results show that, of the covariates included in model analysis, only month and year account for any variation in numbers of Pochard at the Western Section. In years pre-construction, the effect of 2009 for the spring/summer months is positive yet for autumn/winter, it is negative. This statistically supports the observed monthly variation seen in Figure 6.19.

For years during construction, 2011 is a negative predictor during both time periods and is likely due to this species being predominantly located on the Main Section.

Table 6.7: Summary results of GLM for Pochard pre-construction (2006 – 2009) and during construction (2010 – 2013). Analysis split between months spring/summer (April – September) and Autumn/winter (October – March).

Period	Time period	Variable	Estimate	Standard error	z value	P value	Relationship
Pre - construction	April - September	2009	0.682070	0.175857	3.879	<0.001	+
		August	1.814543	0.848173	2.139	<0.05	+
	October – March	2009	-1.4801	0.3616	-4.093	<0.001	-
		March	-1.4897	0.6341	-2.349	<0.05	-
		November	-0.6667	0.3455	-1.929	<0.05	-
		October	-2.4886	0.4241	-5.868	<0.001	-
During construction	April - September	2011	-0.66729	0.25278	-2.640	<0.01	-
		August	1.46906	0.23631	6.217	<0.001	+
		July	1.42196	0.25688	5.536	<0.001	+
		June	1.30597	0.29137	4.482	<0.001	+
	October - March	2011	-0.7542	0.2339	-3.224	<0.001	-
		2013	0.6937	0.2764	2.510	<0.01	+
		February	0.8842	0.3351	2.639	<0.01	+
		November	0.9111	0.3252	2.802	<0.01	+

Kernel density estimation (Figure 6.20) for Pochard reveals distinct distributional similarities with Tufted Duck, particularly for the April – September months; a likely result of mixed flock roosting and similar habitat preferences. The creation of additional habitat, specifically on and around the islands to the south of the Western Section however appears to have appealed to Pochard to a greater extent than Tufted Duck, particularly during the spring/summer months. Analysis to determine if use of the area statistically differed following habitat creation proved non-significant (Mann-Whitney U test).

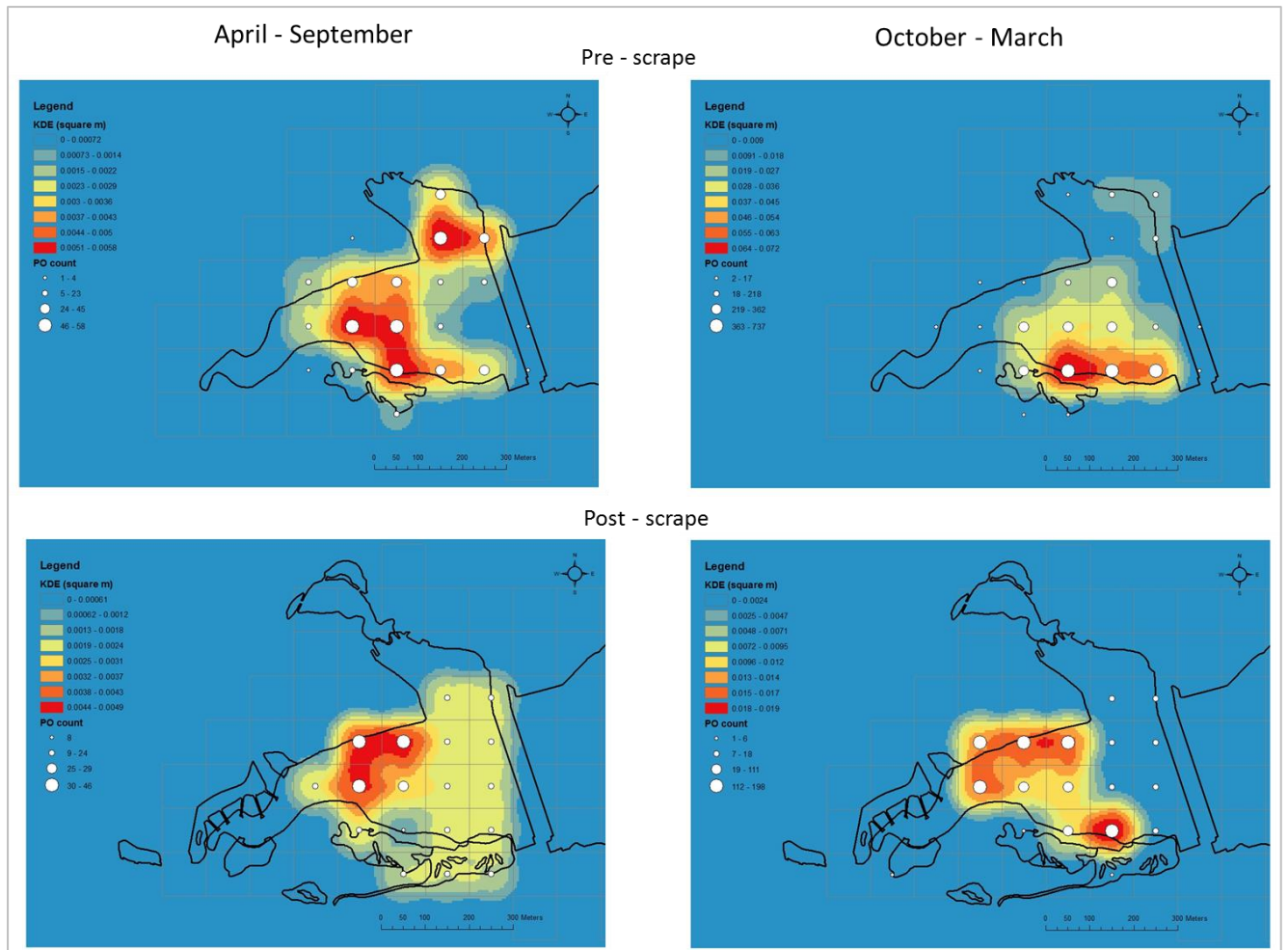


Figure 6.20: Kernel density estimation plots showing the density of Pochard at the Western Section prior to and post habitat creation. Data are merged to represent the April – September and October – March periods and shown with the Refgrid layer. Density units represent the density of Pochard per unit area (per m^2).

Although Pochard did use the new habitat during the spring/summer months, the total number of 100 m^2 Refgrid cells they occupied only increased by one post creation. That said, the frequency with which they occupied each cell increased (Figure 6.21), further demonstrating that this species consistently favours certain areas of the Western Section, notably the J, K and L cells.

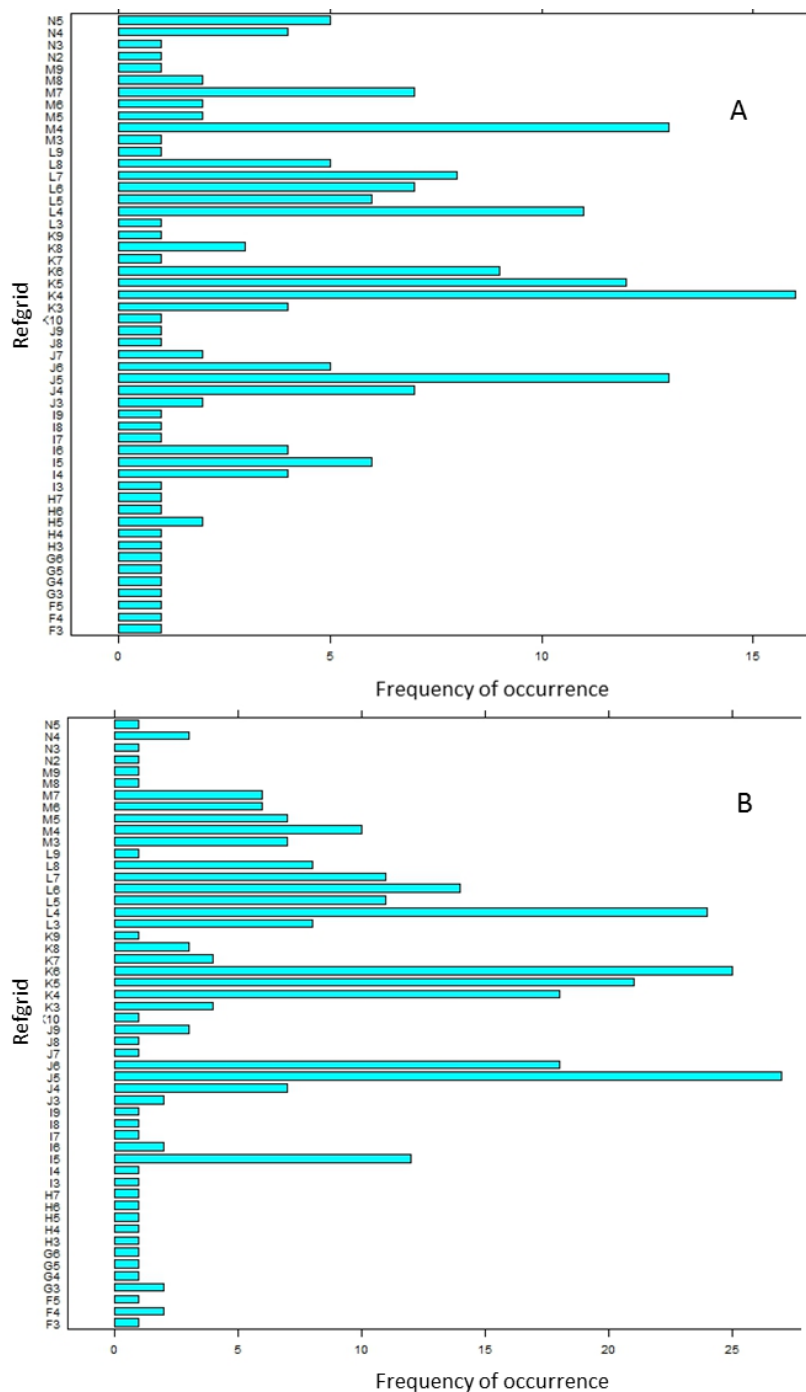


Figure 6.21: Frequency of occurrence of Pochard within each Refgrid cell pre (A) and post scrape construction (B).

6.4.8 Mute Swan

For the combined months of April – September, numbers of Mute Swan at the Western Section were significantly higher for years 2006 – 2009 compared to 2010 – 2013 (Chapter 4). The percentage of

population supported by the area also decreased during construction as shown by Figure 6.22. In contrast, the Western Section supported a higher percentage of the overwintering population during construction, although this varied depending on the year.

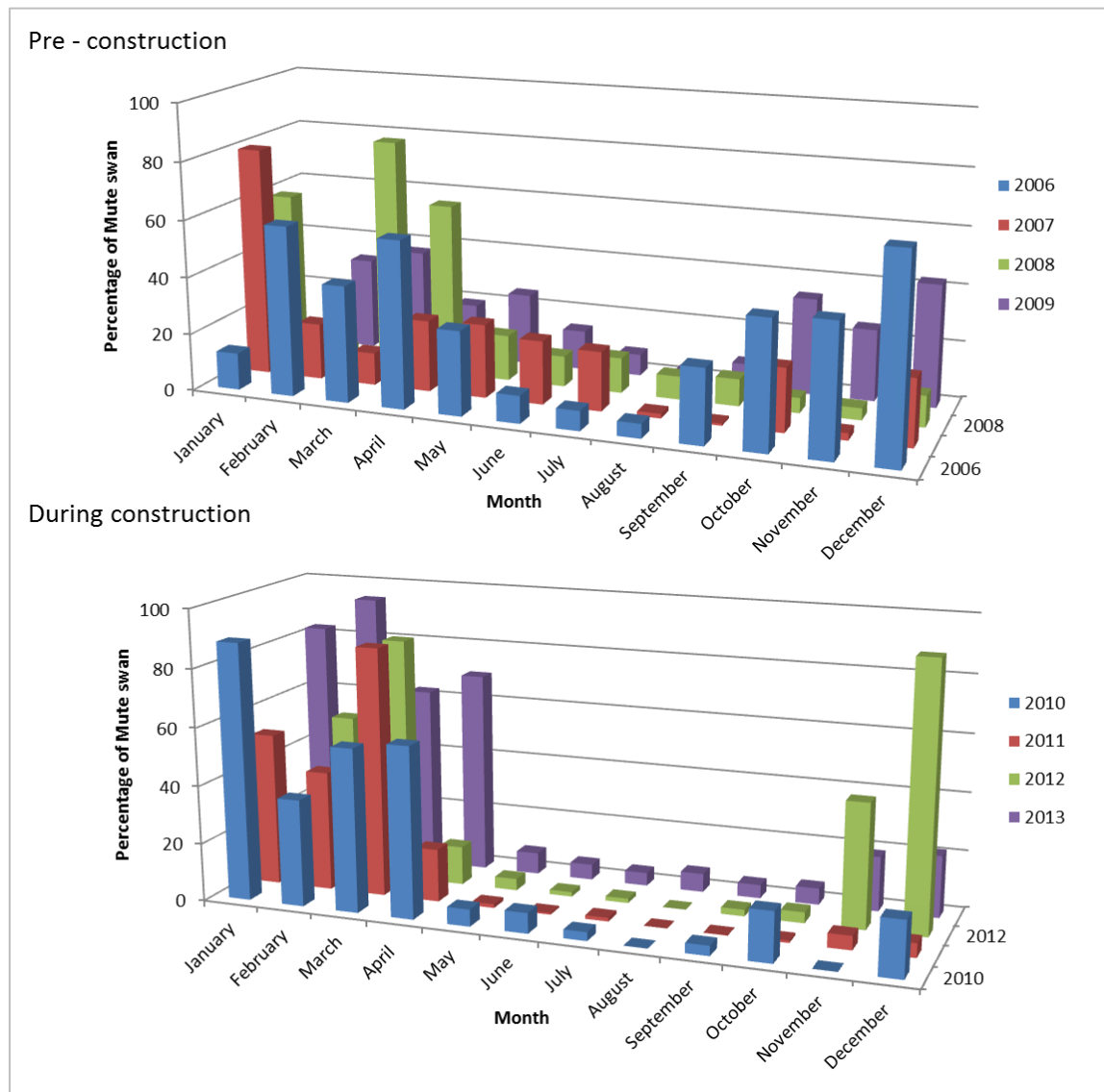


Figure 6.22: Percentage of the Abberton Reservoir Mute Swan population present within the Western Section for years pre-construction (2006 - 2009) and during construction (2010 - 2013).

Results of GLM analysis summarised in Table 6.8 show that pre-construction, numbers of Mute Swan were positively influenced by the months of July and October, but the effect of increasing macrophyte cover was negative. This is in contrast to Hurdle model findings (Chapter 5) which

predicted the chance of a Mute Swan count outcome significantly increasing with higher percentage macrophyte cover.

Table 6.8: Summary results of GLM for Mute Swan pre-construction (2006 – 2009) and during construction (2010 – 2013). Analysis split between months spring/summer (April – September) and Autumn/winter (October – March).

Period	Time period	Variable	Estimate	Standard error	z value	P value	Relationship
Pre-construction	April - September	July	0.5520	0.2158	2.558	<0.01	+
		Macrophyte	-0.5927	0.1108	-5.352	<0.001	-
	October – March	October	1.06486	0.20793	5.121	<0.001	+
During construction	April - September	August	0.78077	0.34865	2.239	<0.05	+
		July	1.02046	0.23755	4.296	<0.001	+
	October - March	2011	-1.09013	0.29247	-3.727	<0.001	-
		February	1.49214	0.23703	6.295	<0.001	+
		January	0.44486	0.23017	1.933	<0.05	+
		March	0.95551	0.23373	4.088	<0.001	+

Upon further investigation, the macrophyte result presented here is due to high counts of Mute Swan occupying areas of land surrounding the Western Section (Figure 6.23). This mapping function uses the count data to calculate and visualise density distributions and also highlights an area of the causeway separating the Central and Western Sections as a favoured spot.

Additionally, density mapping shows that during October – March and compared with years pre-scape creation, both the density and spatial distribution of Mute Swan increased following habitat enhancement. The difference between Mute Swan counts pre and post habitat creation (all months combined) is highly significant (Median pre-habitat = 0, post habitat = 4.5, Mann Whitney $U_{941.5}$, $p = <0.00$).

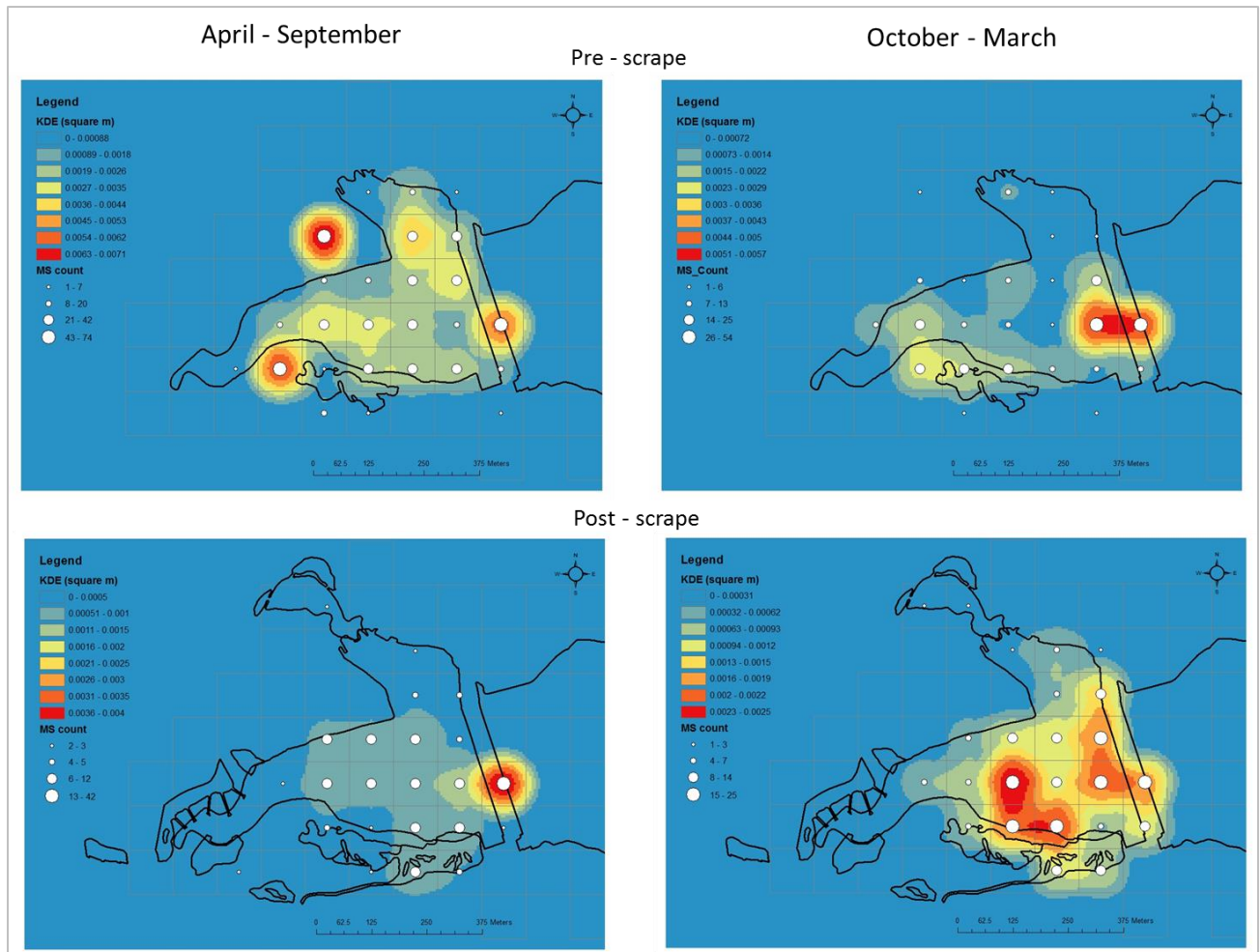


Figure 6.23: Kernel density estimation plots showing the density of Mute Swan at the Western Section prior to and post habitat creation. Data are merged to represent the April – September and October – March periods and shown with the Refgrid layer. Density units represent the density of Mute Swan per unit area (per m²).

Increased use of the Western Section for the overwintering period likely accounts for the greater frequency with which this species occupied individual 100m² Refgrid cells post habitat creation (Figure 6.24). In addition to frequency occurrence, the number of cells containing Mute Swan increased from 30 to 37, although the most consistently occupied areas largely remained the same for both scenarios.

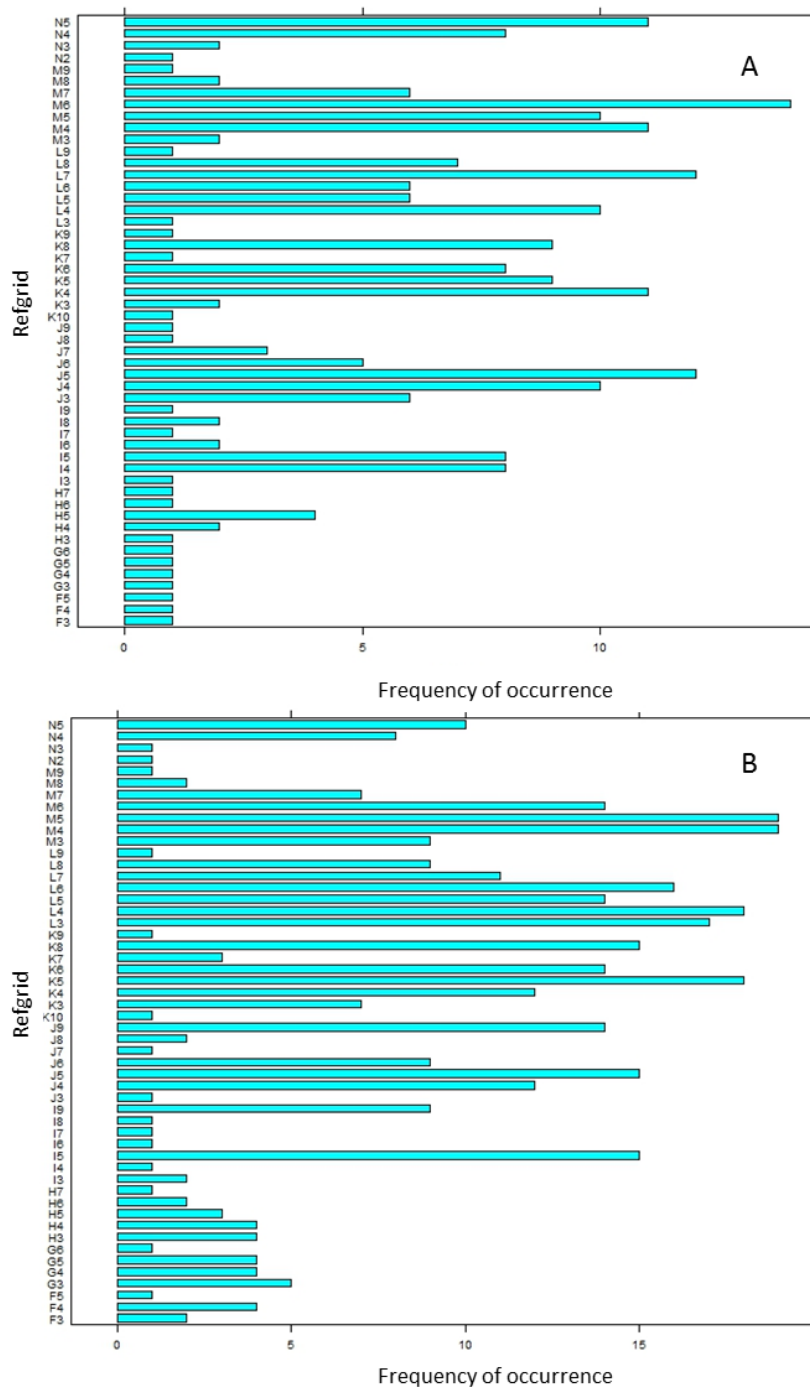


Figure 6.24: Frequency of occurrence of Mute Swan within each Refgrid cell pre (A) and post scrape construction (B).

6.4.9 Great Crested Grebe

Displacement habitat created at the Western Section was designed to primarily benefit the dabbling duck species, yet Great Crested Grebe benefitted with numbers for this section significantly higher

during construction. These results may be a consequence of disturbance given that increase occurred during the active construction months. However, since simultaneous declines were not observed for either of the other two sections, it is considered unlikely. This is supported by Figure 6.25 which shows the percentage of the Great Crested Grebe population occupying the Western Section to be similar for year's pre and during construction. A general increase in the Abberton Reservoir population is therefore proffered as an explanation for results found from this study.

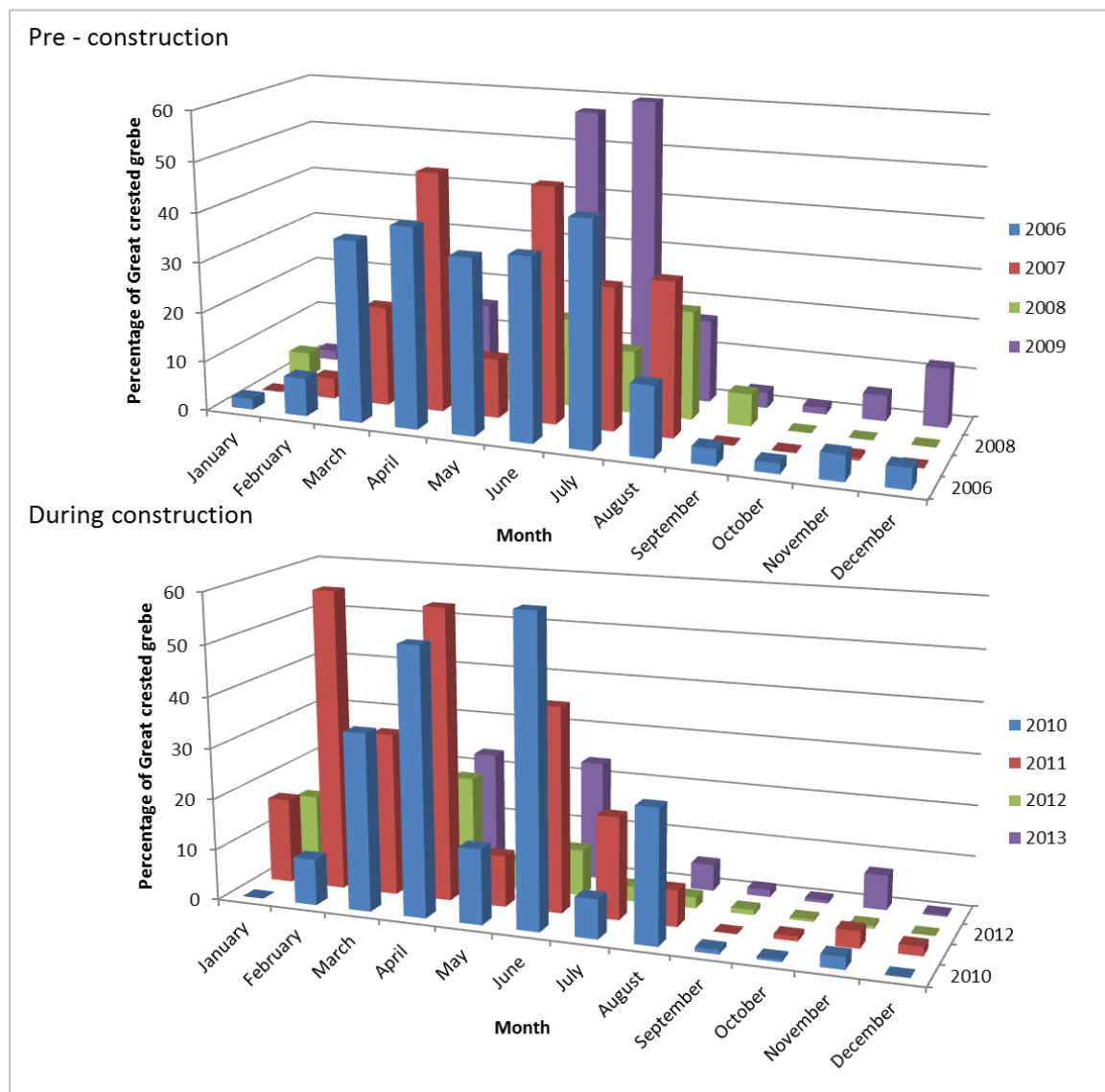


Figure 6.25: Percentage of the Abberton Great Crested Grebe population present within the Western Section for years pre-construction (2006 - 2009) and during construction (2010 - 2013).

Analysis for Great Crested Grebe differs from other species in that a quasi-poisson GLM, opposed to a negative binomial GLM was used (see Chapter 3: Section 3.2.3). Results are varied (Table 6.9) and may partly be a consequence of low observations as, unlike the Main Section, large aggregations of Great Crested Grebe are absent from the smaller Western Section. For years pre-construction, 2008 was found to be a positive predictor on numbers of Great Crested Grebe, while the effect of October, November and increasing macrophyte cover is negative.

During construction for the April – September period, increasing distance to the shoreline was found to exert a positive influence on numbers of this species; likely due to their preference for open water. Analysis for the autumn/winter months did not find any significant variables accounting for numbers of Great Crested Grebe at the Western section.

Table 6.9: Summary results of GLM (quasi-poisson) for Great Crested grebe pre-construction (2006 – 2009) and during construction (2010 – 2013). Analysis split between months spring/summer (April – September) and Autumn/winter (October – March).

Period	Time period	Variable	Estimate	Standard error	z value	P value	Relationship
Pre-construction	April - September	2008	0.24870	0.10751	2.313	<0.05	+
		Macrophyte	-0.16490	0.08454	-1.951	<0.05	-
	October - March	November	-0.67474	0.25502	-2.6465	<0.01	-
		October	-0.79076	0.29747	-2.658	<0.01	-
During construction	April - September	Distance to shoreline	3.262e-03	1.585e-03	2.058	<0.05	+
	October – March	Non-significant	NA	NA	NA	NA	NA

Results of further statistical analysis to compare numbers using the Western Section pre and post habitat creation were also non-significant, although the mean count for the latter years was higher. Kernel density estimation outputs (Figure 6.26) support results presented above and show that the

higher densities of Great Crested Grebe were located in the centre of the Western section, in areas containing the deepest and most open water.

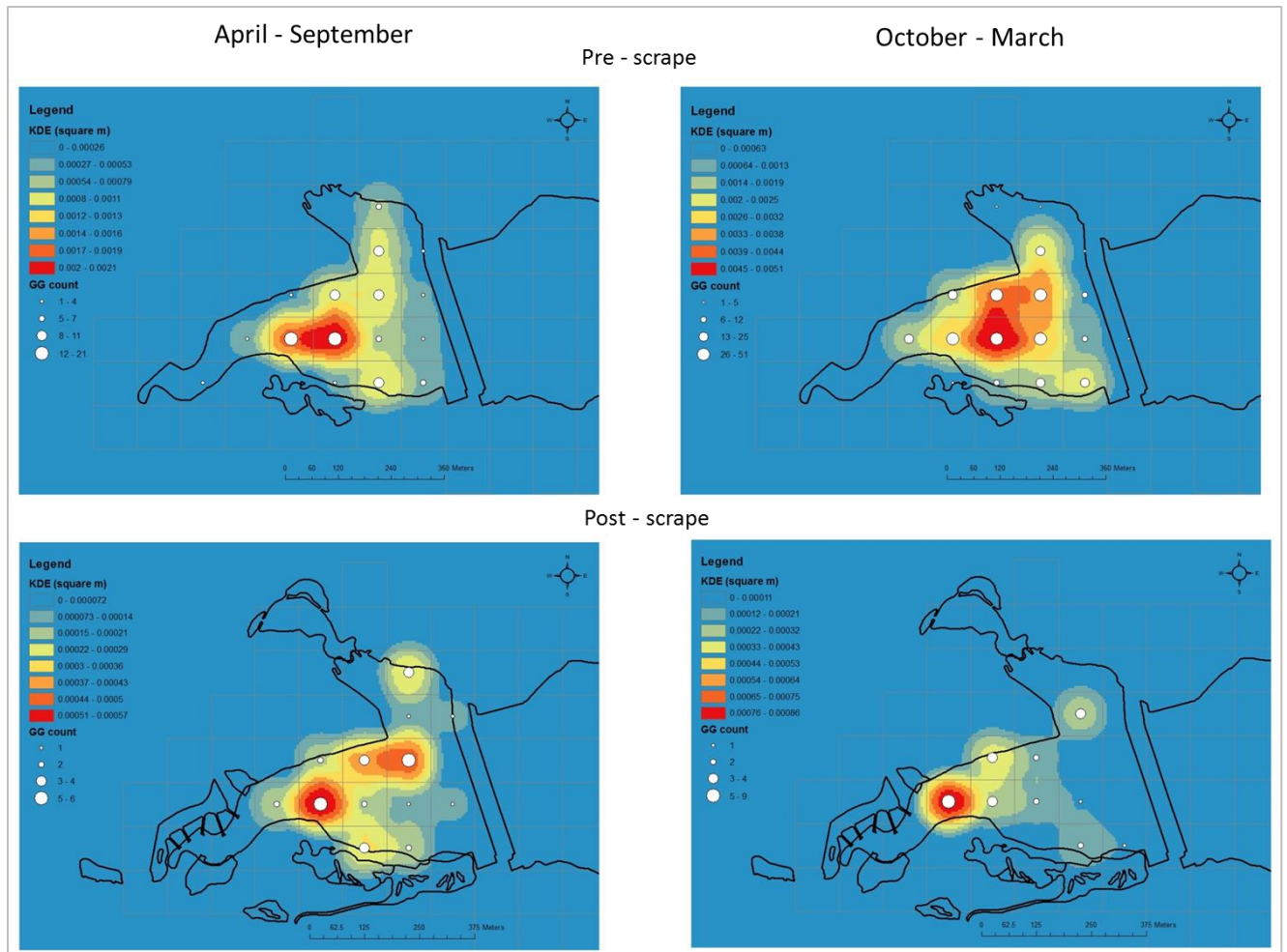


Figure 6.26: Kernel density estimation plots showing the density of Great Crested Grebe at the Western Section prior to and post habitat creation. Data are merged to represent the April – September and October – March periods and shown with the Refgrid layer. Density units represent the density of Great Crested Grebe per unit area (per m²).

Results thus far for this species show that numbers were higher at the Western Section during construction, but not necessarily as a direct consequence of habitat enhancement. Assessing the frequency occurrence of this species in Refgrid cells pre and post creation challenges that finding since both the number and frequency of cells occupied increased following creation (Figure 6.27). Of course this may however be coincidental and a result of increasing numbers at the site which has been linked to enhancement of the Main section during construction.

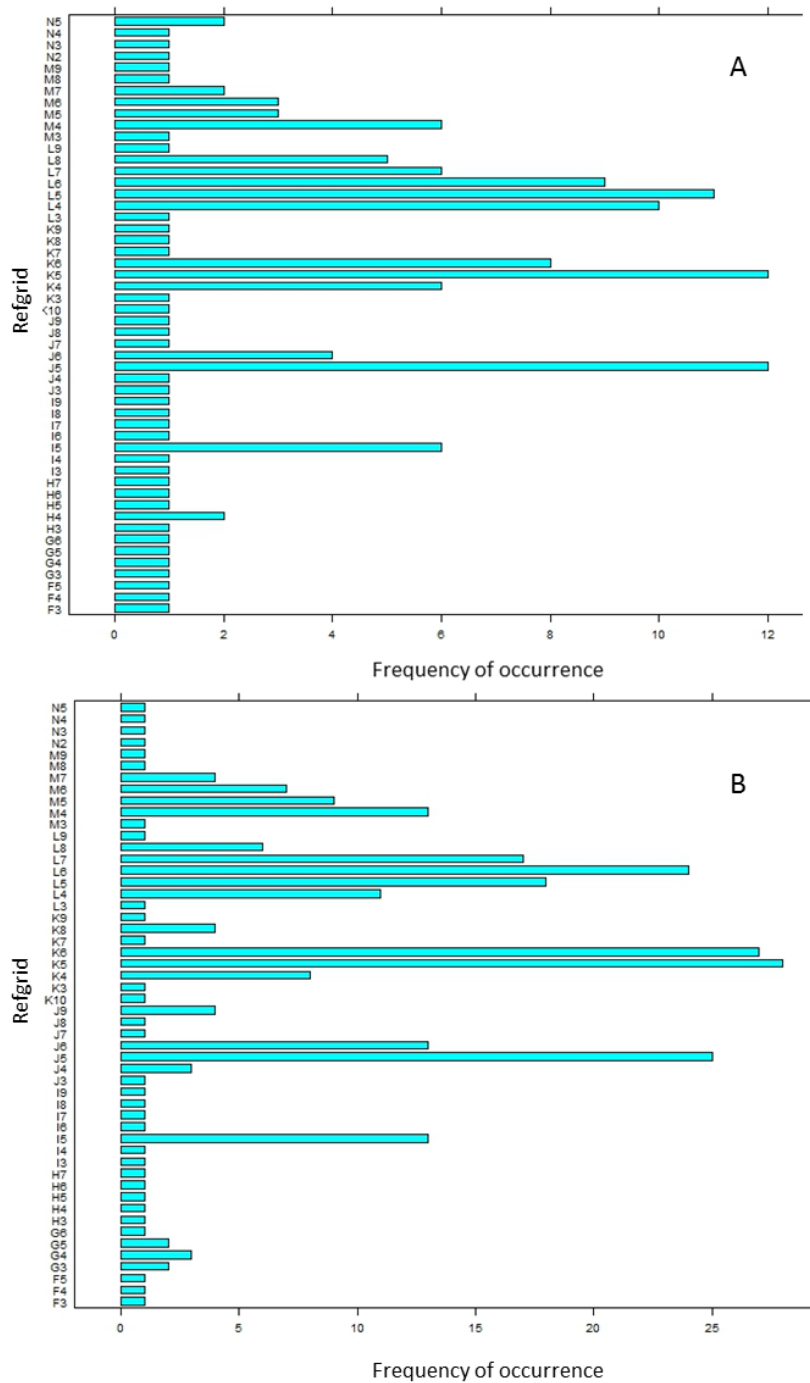


Figure 6.27: Frequency of occurrence of Great Crested Grebe within each Refgrid cell pre (A) and post scrape construction (B).

6.5 Discussion

6.5.1 Summary

In autumn 2008, approximately 6ha of wetland habitat, designed to accommodate waterfowl displaced from the Main Section as a result of construction of the Abberton Scheme, was created at the Western Section of Abberton Reservoir. To determine use and efficacy of the created mitigation habitat, the spatial distribution of nine Abberton SPA waterfowl species was assessed for years prior to, and following habitat creation for the temporal periods April – September, October – March and in relation to construction activity. A combination of parametric and non-parametric statistical methods was used to quantify differences in use of the habitat by each species and to determine the influence of environmental variables. Additionally, Kernel Density Estimation and spatial mapping tools were used to facilitate comparisons between each spatial and temporal period.

Results show that all nine SPA species utilised the new habitat with numbers of Gadwall, Coot, Mute Swan and most notably Teal, significantly increasing post habitat creation; most likely due to an increase in shallow water and the introduction of islands providing habitat not previously available. Unsurprisingly, given their affinity with open water, the addition of shallow scrape habitat was of limited benefit to Tufted Duck, Pochard and Great Crested Grebe. Findings support conclusions from previous results chapters with increased use of the Western Section associated with disturbance resulting from construction of the Central Section causeway and with activities extending beyond the April – September window. Results also support existing literature in that success and immediate use of the new scrapes is in part, attributed to its location and connection to an existing and mature water body.

6.5.2 Gadwall

Throughout the eight year study period the Western Section was found to be consistently important to Gadwall during the summer months, with a clear shift observed for the overwintering period. For these months during years of construction, the Western Section supported a higher percentage of the Abberton Reservoir Gadwall population which statistical analysis and density mapping showed to be attributed to increased use following creation of displacement habitat. Prior to enhancement, the edge of the Western Section contained a concrete boundary fence bordered by either arable or grazing land with the inner, water based margins, predominantly featuring scrub and reedbed. The creation of lagoon and scrape habitat surrounding this section and the introduction of islands opened the shorelines and created roosting opportunities not previously available. In combination with a greater extent of shallow water, the appeal of this area to Gadwall is attributed to the inclusion of these features.

Ultimately, the aim of habitat creation at the Western section was to provide any waterfowl (principally Gadwall, Shoveler and Teal) with on-site mitigation habitat should they be displaced as a result of construction works. Whilst results have shown limited disturbance to Gadwall from the Main Section; largely due to its size and sensitive programme design, a disturbance effect from work on the B1026 causeway was noted. Hurdle and GLM analysis revealed the effect of 2012 and to a lesser degree 2013, to be associated with low Gadwall counts. These years coincide with the most disturbing causeway works which together with areas of the main dam and off-take pumping station, were locations of disturbance that continued beyond the April – September window. Analysis has shown a simultaneous increase in use of the Western Section (in terms of percent of the population) and a decline in the once favoured Central Section for the autumn/winter months (October – March). Together with knowledge of an enhanced causeway disturbance effect and low numbers in 2012, it is concluded that the Western Section functioned as suitable mitigation habitat

for Gadwall during the over-wintering period as a result of enhanced site appeal and displacement from the Central Section.

Additionally, results presented here support observations that Gadwall can adapt to changing site conditions (Briggs et al., 2012) and quickly utilise new habitat providing there are sufficient resources. Evidence from creation and restoration schemes indicate that it is necessary to have a particular species in mind rather than assume any new habitat is beneficial (Atkinson, 2001b). Given the increase in shallow water habitat and natural edges at Abberton Reservoir, both at the Main Section following re-profiling works and the creation of scrape habitat at the Western Section, there is evidence to suggest that any mitigation habitat created for Gadwall should focus on these key features.

6.5.3 Shoveler

Results show that for the months of October to March and compared to years pre-construction, higher numbers of Shoveler were observed for the Western Section during construction. This increase was not shown to be directly associated with creation of displacement habitat suggesting that construction activities on the Main Section and from the B1026 causeway resulted in displacement of Shoveler to the Western Section. However, this is not supported by construction disturbance assessment, which identified the Main Section as a positive predictor of Shoveler and unlike other species; numbers of Shoveler were shown to increase within the Central Section for years during construction.

Although there is limited evidence to support a displacement theory, there is evidence to suggest that Shoveler spent more time feeding on the Main Section during construction compared to years pre-construction. Shoveler have an adaptive feeding strategy (Cramp and Simmons, 1977) depending on prey and site conditions, but predominately feed by straining the water for zooplankton. Should prey become limiting, which typically occurs over the winter months

(Guillemain et al., 2000b) Shoveler will “up-end” and shift to feeding on benthic organisms, ultimately abandoning the site if conditions decline. Results suggest prey was not a limiting factor at the Main Section during construction however increased feeding may have been a disturbance response or purely a consequence of resource utilisation. Use of the Western Section by Shoveler differed from the Main Section and between the two study periods, with density mapping suggesting birds were principally using the area following displacement habitat creation as a roosting refuge. This is demonstrated by high densities and increased frequency of occurrence for 100m² Refgrid cells of Shoveler located on and around the new islands and shorelines. Whilst this this may have been due to disruption of roosting habitat on the Main Section, analysis shows these areas were favoured in both April – September and October – March periods and suggests that the addition of islands and shallow/bare edges provided additional moulting and winter roosting opportunities.

6.5.4 Teal

Previous chapters have reported significant differences in numbers of Teal using the Main and Central Sections pre and during construction, however, only when data were separated between pre and post displacement habitat creation were differences for the Western Section found. Numbers of Teal significantly increased following habitat creation which was observed for both April – September and October – March periods. Similar to Gadwall, this demonstrates that newly created habitat is quickly utilised by Teal supporting the view that mobile species such as birds are often the first to respond and colonise new habitats (Atkinson, 2001b).

Creating habitat at the Western Section was specifically designed to accommodate dabbling duck should they be displaced from the Main Section during construction and although some disturbance impacts are reported, crucially it did not cause displacement from the Main Section. Results show that use of new habitat at the Western Section significantly increased following creation of

displacement habitat. Therefore, had disturbance been more of an issue, it is likely the area would have functioned as sufficient mitigation habitat for this species.

In considering the results and views taken by previous authors, it is highly likely that success of the Western Section scrapes for the target species is due to its location and connection to an existing and already used water body. When the walls surrounding the Western Section were breached, water flooding the new areas was already rich in prey items, specifically zooplankton and chironomid larvae which have been linked to habitat use and numbers of dabbling duck including Teal (Gardarsson et al., 2008).

6.5.5 Wigeon

Spatial distribution analysis (Chapter 4) for Wigeon showed a highly significant decline occurred at the Western Section during construction for the months of October – March. Counts simultaneously declined for the Central Section yet overall numbers were maintained, reflecting increased Main Section occupancy. An exception was during the active construction months of April – September in 2010 and 2011 when increased numbers of this species were observed for the Central Section. This coincides and has been attributed to high magnitude disturbance events occurring on the shorelines around the Main Section.

Analysis to differentiate between pre and post habitat creation (Western Section) was non-significant suggesting that the created displacement habitat was not beneficial for this species. Furthermore, although numbers of Wigeon are reported as lower in years pre-construction, the Western Section between May and August supported almost 100% of the Abberton Reservoir population. This level of use was not achieved during years of construction activity. Due to relatively low Wigeon counts over the study period, GLM analysis included all months of the year with the only significant covariates shown to influence Wigeon being year and month. Unlike findings reported in the previous chapter, Wigeon did not show any particularly strong affinity to areas close to the

shoreline. This was surprising as Kernel density estimation mapping showed high densities were present on the islands and shorelines of the Western Section. Given this, it is possible that low numbers and variation in monthly counts reduced the strength of the shoreline relationship and demonstrates that with species showing a complicated and highly variable distribution, several analytical methods are beneficial.

Results may also be explained by this species habitat and feeding requirements. Wigeon are almost exclusively herbivorous and require a high food intake and prolonged feeding period compared with other wildfowl (Mayhew, 1988). They require large areas of undisturbed established grassland with abundant seed bearing species to fulfil their energetic requirements, particularly during the winter months. The newly created and relatively small extent of Western Section habitat may not have been sufficient. Additionally, large numbers of geese frequent the grasslands surrounding the Western Section which may have increased competition and reduced the appeal of this area to Wigeon. This would also explain the preference for the Central Section in early years of construction as the established margins would have provided a plentiful food supply as well as safe roosting.

6.5.6 Coot

Analysis from this study revealed the Western Section to be particularly important for Coot during the months of June and July; a relationship shown for both study periods. Higher percentages of the Coot population were however present pre- construction, which may be attributed to increased numbers on the Main Section during construction. The seasonal use of the Western Section suggests that at certain times of the year, the area provides Coot with a habitat not available on the other sections. The bordering reedbed and stands of emergent vegetation provides a likely explanation given plant community structure has been linked to wetland status (Wall and Stevens, 2014).

Although numbers of Coot are reported as higher during construction, 2013 was a particularly bad year, with Hurdle and GLM analysis associating it with lower counts. Whilst construction activity may

have influenced use of Abberton Reservoir by this species, declines during winter 2013 were seen elsewhere including at Rutland Water which, notwithstanding Abberton Reservoir, is regarded as the most important site in Britain for Coot (see Appendix 4.4). Analysis to investigate any differences in counts pre and post displacement habitat creation showed that the creation of additional wetland in this area benefited Coot, with numbers significantly higher following enhancement. This was observed for both April – September and October – March periods but was not identified in previous analyses (Chapter 4). Consequently, and in light of increased numbers for the Main Section during construction, results suggest that increased use of the area was not linked to disturbance on the Main Section.

Kernel density estimation revealed that Coot utilised much of the available wetland area and an increase in numbers of 100m² Refgrids post creation was observed - a result of Coot using the most southerly created scrape. Despite increased spatial distribution and evidence to suggest Coot were utilising the recently formed islands with the highest densities of Coot observed for the original body of the Western Section, a likely result of this species aggregating on the open water.

6.5.7 Tufted Duck

The decline in Tufted Duck at Abberton Reservoir during construction was unexpected, with further analysis showing that during this time, the percentage of the population the Western Section supported also declined. The exception was 2010 and June 2011, when 60% of the population resided in the Western Section. This may be linked to construction activity given that 2010 marked the start of active works and shoreline re-profiling occurred throughout 2011.

Statistical modelling revealed January and February to be constant positive predictors for numbers of Tufted Duck at the Western Section. This reflects the high numbers of waterfowl during the overwintering period, the time period for which Abberton Reservoir is primarily designated. The Western Section, although small in spatial extent, offers a degree of protection from predation and

harsh weather courtesy of the reedbeds and vegetated margins; likely to appeal during the colder months when conserving energy is of critical importance.

Data analysis did not show any statistically significant differences in use of the Western Section pre and post displacement habitat creation although counts and densities were higher for the former years. This suggests enhancing the area was of limited benefit to Tufted Duck although plotting the frequency occurrence of each Refgrid cell shows that both the frequency and number of occupied cells increased following habitat creation. Despite additional Refgrid use, across all eight years, Tufted Duck showed a preference for cells containing open (and the deepest) water. This was also reported for the Main Section and although potentially axiomatic with respect to diving duck, demonstrates a clear habitat preference and explains why the displacement habitat was of limited benefit to this species.

Tufted Duck are known to feed on mussels (Leeuw et al., 1999, Oka et al., 1999, Werner et al., 2005, Van Nes et al., 2008) which take many years to colonise and grow to a size that are suitable for waterbirds (Atkinson, 2001b). This offers another explanation for the limited use of the scrapes by Tufted Duck and is supported by studies showing that differences in bird assemblages were attributed to food resources, with bivalve feeding species the slowest to utilise new habitat (Atkinson et al., 2004). The inclusion of deeper water at the Western Section would therefore have benefited this species; although shallow water is also required, since these habitats are often nursery grounds for prey. Many benthivores therefore ultimately also depend on the preservation of shallow water areas (Clausen and Clausen, 2014).

6.5.8 Pochard

Over the eight year study period the Western Section consistently supported the majority of the Abberton Reservoir Pochard population between December to February and May to July. The annual pattern was remarkably similar across all years with the lowest percentages observed for April and

September. The Western Section, unlike the other two larger water bodies provides a relatively stable environment; reflected by the consistency with which Pochard use the area. Furthermore, aggregations of this species are known to favour open water bodies fringed with aquatic vegetation, which is abundant within this Section (Cramp and Simmons, 1977).

Pochard and Tufted Duck occupy a similar ecological niche and at Abberton Reservoir, can frequently be observed roosting in a mixed 'diver' flock. It is therefore unsurprising that the distribution and density pattern for Pochard during April – September resembled that of Tufted Duck; a pattern also seen in spatial distribution analysis. Although distributional similarities between the two diving species are observed and they both mainly feed on molluscs, they use food resources differently with Pochard foraging on larger mussel specimens that can deplete quicker than the smaller ones eaten by Tufted Duck (Sekiya et al., 2000). Consequently, these authors concluded that Tufted Duck use wintering areas for longer periods than Pochards which move when resources deplete. This has not been observed at Abberton Reservoir and suggests a plentiful food supply as well as sufficient roosting opportunities exist at the Western Section. However, analysis has not specifically attributed this to creation of the displacement habitat; as the number of occupied Refgrid cells only increased by one post creation although the frequency of occurrence for individual cells was higher.

6.5.9 Mute Swan

Supporting findings from Chapter 4, during the spring/summer month's higher percentages of the Abberton Mute Swan population were present within the Western Section in years pre-construction. During the autumn/winter months however, the Western Section supported a higher proportion of the population during years of construction activity. In contrast, findings from GLM analysis conflict with Hurdle model results, which showed Mute Swan at the Main Section to be positively associated with high macrophyte cover, whereas at the Western Section, for the months April – September, numbers declined with increasing plant cover. Upon further investigation and utilising the Kernel

density estimation function, this result was due to high counts being located on fields surrounding the Western Section and not on the water body itself.

The Mute Swan is a large native herbivore (Rowell and Spray, 2004) and has been linked to declines in macrophyte abundance, biomass and community structure (O'Hare et al., 2007, Gayet et al., 2011). However, this species will also feed and cause damage to some arable crops (Wood et al., 2014). Land surrounding Abberton Reservoir is predominately arable and as crops start to grow, Mute Swans take advantage and feed on the nutrient rich young plants. This foraging behaviour explains the Western Section results observed for the April – September pre-construction months, with aggregations located on the northern arable fields in April (2006 and 2008) and on the grassland near the trial scrape in September (principally during 2006).

Density mapping also further illustrated increased use of the Western Section during the overwintering period post habitat creation; a result found to be highly significant. For these months, the number of occupied 100m² Refgrids increased and the frequency occurrence was higher. Results from disturbance analysis reported a decline in use of the Central Section, yet overall site numbers remained consistent. Combined results support the Central Section disturbance theory (for spring/summer and autumn/winter months) with Mute Swan moving to the Main and Western Sections. That said, it is likely that enhancement works to both the Main and Western Sections was attractive to Mute Swan, in which case habitat creation and mitigation measures for these two sections and for this species, can be reported as successful.

6.5.10 Great Crested Grebe

Spatial distribution analysis reported a significant increase in numbers of Great Crested Grebe at the Western Section during construction though the proportion of the total population within the section was similar between the two study periods. This suggests a general increase in numbers occupying the site and is supported by WeBS data for Abberton Reservoir (Appendix 4.4).

Although increased numbers are reported for years during construction, the difference between pre and post displacement habitat creation was non-significant, therefore statistically, higher numbers cannot be directly attributed to enhancement of the Western Section. Nevertheless, there is evidence to suggest the new areas were of benefit to Great Crested Grebe as the number and frequency occurrence of each 100m² Refgrid increased following creation. That said, the Western Section is comparatively small and birds would be expected to utilise any new areas of water.

Results indicate that the way in which this species used the Western Section differed to the Main Section in that counts for each Refgrid were relatively low; possibly a result of a smaller carrying capacity given the section size. This had implications on statistical modelling with data exhibiting under dispersion opposed to over dispersion, which was present for all other analysed species. In response, a quasi-poisson GLM was used to analyse the Great Crested Grebe data. Excluding month and year, macrophyte cover and distance to shoreline were found to influence this species during the spring/summer months. The relationship with macrophyte cover was negative whereas the effect of increasing distance to shoreline was positive; results are attributed to this species showing a preference for open water.

Flock-fishing, where a tight group of birds move in a coordinated way (Kallander, 2008) was proffered as an explanation for dense aggregations of this species in the Main Section, with birds utilising the vegetated transitional zone between shallow and deep water. Excluding water body size as an explanation, the dispersed distribution of Great Crested Grebe in the Western Section suggests that the ecology of this section is different. Layer Brook, to the west of the site, feeds the Western Section and is at times laden with suspended solids and sediment which then settles out in the water body. The relative shallowness of the section and years of sediment accumulation is likely to have affected water clarity and therefore also the feeding strategy of the piscivorous Great Crested Grebe. Given that high water transparency is thought to compensate for low prey density (Gwiazda, 2009), it is probable that although the Western Section has reduced water transparency, prey

density is high. This is supported by observations of the shallow areas of the section, especially a long ditch, acting as a fish nurse (author observations).

6.6 Conclusions

Waterfowl data representing eight years and nine Abberton Reservoir SPA species was analysed for the Western Section of the reservoir using generalized linear modelling (GLM), Kernel density estimation (KDE) and percentage and frequency occupancy techniques. Count data for the months of April through to September and from October through to March (2006 – 2013) were used to determine differences in use by waterfowl of the Western Section in relation to construction activity and in response to creation of the Abberton Scheme displacement habitat, ultimately assisting in determining the success of the Abberton Schemes mitigation measures. Results show that all SPA waterfowl species utilised the newly created areas, evidenced by KDE and an increase in the number and frequency occurrence of 100m² Refgrid cells. The increase following displacement habitat creation was statistically significant for Gadwall, Teal, Coot and Mute Swan with Teal showing the most dramatic increase.

Mitigation for the Abberton Scheme was targeted in its approach, identifying three dabbling species as being most at risk from construction disturbance impacts. Overall, analysis suggests that creation of displacement wetland at the Western Section was of benefit to the target species, although Shoveler to a lesser extent as compared to Gadwall and Teal. Increased use of the area by Gadwall is attributed to the inclusion of suitable habitat at the Western Section and displacement from the Central Section in response to construction works from the B1026 road diversion and raising of the causeway embankment. Displacement from the Main and Central Sections during construction was not noted for Shoveler although there is evidence to suggest a behavioural change which is a likely response to construction disturbance. Following habitat creation at the Western Section, Shoveler showed a preference for areas containing islands which provide a safe refuge, particularly during the moulting and overwintering period when waterfowl typically spend more time roosting in order to conserve energy (Fox and King, 2011). The shallow margins and islands of the southern scrapes were also occupied by Teal and numbers were shown to significantly increase following habitat creation

though this was not as a consequence of displacement from the Main Section. Given these two results, there is strong evidence to suggest that the design and inclusion of shallow water habitat, both at the Main and Western Sections was advantageous to this species.

Results show that the programme timings and habitat creation incorporated into the Abberton Schemes design as mitigation, were successful in limiting disturbance impacts and maintaining site integrity for Gadwall, Shoveler and Teal. The exception is the Central Section for which disturbance impacts were notable, both during the active construction period (considered to be April – September) and overwinter (October – March). This is attributed to the relative small and homogeneous nature of the Central Section, whereas the size and diversity of habitats offered by the Main Section enabled re-distribution of waterfowl within that section to a changing environment without causing significant adverse effects. The displacement habitat, given its relatively small extent, would not have supported high numbers of relocating waterfowl which ultimately would have resulted in site deterioration. Furthermore, and reinforcing conclusions from the previous chapter, it is highly likely that significant and potentially irreversible disturbance impacts would have occurred had construction activity progressed at the same magnitude during the overwintering period as was incurred over the quieter spring/summer period.

The success of displacement habitat was more varied for the other analysed SPA species which have a diverse range of habitat and feeding requirements. Wigeon are considered to be within the dabbling duck guild, however, they were excluded from displacement habitat calculations because they are principally a terrestrial grazing species and any displaced birds were expected to fly to nearby fields. Despite a significant decline observed for the Western Section in Chapter 4 analyses, results were non-significant when data were split between pre and post habitat creation suggesting the displacement habitat was not of particular benefit to this species. Initially this finding was surprising given the extensive areas of grassland surrounding the Western Section. However, the habitat was fairly immature having been disturbed during creation works in the latter part of 2008.

This implies that in order for compensation or mitigation habitat to be successful for Wigeon, created habitat needs to be mature and diverse enough to provide a range of energy rich food; further highlighting the problematic nature of creating mitigation habitat close to or during project development.

With the exception of Coot which significantly increased following habitat creation, results for the diving species were somewhat more expected, with Tufted Duck and Pochard continuing to predominantly use the open water of the existing main body of the Western Section. Existing research has shown that waterfowl assemblages are relatively low in new habitats for the first two years (Atkinson et al., 2004) which has been linked to geo-chemical recycling, nutrient flow, sediment, maturity of aquatic vegetation and establishment of prey, particularly invertebrates and bivalve species (Zedler and Callaway, 1999, Atkinson, 2001b, Atkinson et al., 2004, West et al., 2005, Stefanik and Mitsch, 2012). The primary reason for creation of displacement habitat prior to the construction phase (and prior to planning permission) was to allow the newly created areas to mature sufficiently enough to accommodate waterfowl. It is probable that two years would not have been long enough had the displacement habitat been created in isolation; expanding the existing water body enabled sediments, fish, invertebrate larvae and vegetation to quickly establish within the new habitat emphasising the need for wetland creation to focus on wetland complexes and not isolated habitats (McKinstry and Anderson, 2002). Additionally, the Western Section scrapes were the location of macrophyte establishment trials undertaken in preparation for the construction phase to assist aquatic vegetation should the existing communities not respond well to raising of the water level. This likely assisted the new habitat in achieving maturity and stability in a quicker time frame than would have been achieved if action had not been taken.

Interestingly, Tufted Duck showed a similar spatial distribution change during 2010 and 2011 to Wigeon and given these two species have completely different habitat requirements, disturbance from concrete removal and shoreline re-profiling on the Main Section is deemed to be responsible.

The STIAA predicted that these activities would be the most disturbing to waterfowl which is supported by this research. Assessments also determined that causeway works would likely result in a disturbance impact, although not to the extent identified by this study.

Designing mitigation habitat to accommodate the needs of a range of species such as those occurring at Abberton Reservoir is difficult. In the UK and EU, there are currently no formal guidelines for best practice in the restoration or creation of new habitats that specifically relate to waterbirds, or recommendations for determining the success of the mitigation mitigation/compensation process (Atkinson, 2001b). Consequently, the extent to which mitigation sites can replace the function of existing wetlands remains uncertain (Gutrich and Hitzhusen, 2004) and like for like habitat creation, in respect of complex ecosystem replacement , simply may not be achievable. The Abberton Scheme was deemed a joint engineering and enhancement project building mitigation into the programme and design. Had significant adverse effects been identified and compensation/mitigation habitat necessary, the land mass required to accommodate multiple species would have been vast, exceedingly costly and almost certainly unsuccessful in maintaining site integrity. Assessments concluded by the STIAA determined that a precautionary and targeted approach was the most appropriate and deliverable mechanism of maintaining the sites conservation objectives throughout the four year construction phase. This targeted and carefully considered approach, where adverse impacts are avoided, should be a required standard, initiated at project conception and development permission only given where the mitigation is deemed satisfactory such that no residual impacts from the development remain. Furthermore, monitoring is essential to improve the approach, understanding and ecological performance of project design, impacts and the performance of mitigation design.

Chapter 7

General Discussion and Conclusions

Overarching conclusions

This research represents an assessment of data for nine Abberton Reservoir SPA waterfowl species spanning an eight year period. The spatial distribution of waterfowl during the four year construction phase of the Abberton Scheme (2010 – 2013) was assessed in relation to construction activity and the influence of environmental variables, notably water depth and food availability (macrophyte cover). Data were compared with baseline information from pre-construction years (2006 – 2009) and any spatial and temporal changes in waterfowl distribution, related to environmental conditions and construction disturbance. To determine the efficacy of created displacement habitat, use of the Western Section by waterfowl species was assessed in relation to construction activity and changes in density, in relation to habitat creation. The significant outputs and findings of this research are broadly summarised as follows.

Influence of habitat heterogeneity and size of wetland

Many studies have indicated that wetland size and structural diversity influences species richness and abundance of waterfowl (Caziani et al., 2001, Paracuellos and Telleria, 2004, Beatty et al., 2014b). In addition to supporting this observation, research presented here demonstrates that size of water body and habitat heterogeneity is fundamental to the ability of a site to absorb disturbance impacts. This is evidenced by the significant differences between responses to construction disturbance by Abberton SPA waterfowl using the Main and Central Sections. The three sections of Abberton Reservoir (Main, Central and Western), distinctly differ from each other, both in terms of size and habitat. This mosaic effect has a positive influence on waterfowl, allowing a variety of species and their temporal requirements to be satisfied; further enhanced by the coastal location of Abberton Reservoir. Broadly speaking, the Main Section of Abberton Reservoir supports high numbers of waterfowl during the overwintering and migratory period, the Central Section becomes important during the autumn months when low water levels expose shorelines, thus providing enhanced feeding opportunities and the Western Section, is occupied primarily during the annual

waterfowl moult. The Main Section is the largest, representing 86% of the total aquatic habitat and was subject to major construction activity over a four year period. Results from this research show that the spatial and temporal distribution of Abberton Reservoir SPA waterfowl aggregations and individual species, varied considerably over the eight year study period, e.g. the total number of Shoveler during 2007 was 1672, increasing to 2529 birds in 2010, with numbers reaching peak levels of 6913 in 2012. Total counts of other SPA species also increased during 2010 – 2013, with numbers of waterfowl (nine species combined to represent the SPA assemblage), shown to significantly increase during construction compared to years pre-construction (Chapter 4: Section 4.3.2.2). This demonstrates that SPA waterfowl aggregations using the site were not displaced from the reservoir complex during construction works. This finding is attributed to the ability of waterfowl to relocate as required, within the reservoir complex. Whilst this does refer to the entire site i.e. the SPA, it is primarily a result of construction works being limited to the Main Section which retained its significance to waterfowl due to its size and habitat complexity. This is supported by results presented here showing that numbers of waterfowl significantly declined within the smaller Central Section, which was associated with construction activities on the B1026 causeway. Declines were found for numerous species, with impacts continuing into the overwintering period (October – March). With the exception of the causeway itself, habitat within the Central Section largely stayed the same as in the pre-construction period i.e. the shorelines were not subject to any re-profiling activities nor were any changes in vegetation reported. It is therefore concluded, that construction activities on the causeway created a greater disturbance effect to the Central Section than observed for the Main Section. This is attributed to the Central Section being smaller (10% of available habitat), and more homogeneous in habitat structure, which likely reduced the carrying capacity and tolerance of waterfowl; ultimately resulting in displacement from this section.

Species sensitivities to disturbance and environmental conditions

The implementation of effective management strategies requires an understanding of a species biological requirements, the spatial responses of that species to disturbance and the consequence of that response (Bennett et al., 2009). As a consequence, the location and magnitude of construction activity for the four years construction period was ranked and mapped and the distribution of nine waterfowl species assessed using Hurdle model analysis (Chapter 5). Results were compared to analysis from years pre-construction and considered against a range of environmental variables.

Results show that sensitivity to construction disturbance at Abberton Reservoir varied amongst species, although a consistent finding was that they maintained a minimum distance of 200m away from high impact shoreline construction activity. This has implications for environmental managers when considering the impacts of site disturbance and should be used to design appropriate mitigation strategies e.g. buffer zones. Another significant, yet unexpected finding was that diving duck were affected to a greater extent than dabbling species. This is in contrast to the literature which generally considers species within the dabbling guild to be the most sensitive (Cryer et al., 1987, Burton et al., 2002b, Pease et al., 2005). However, it is acknowledged that this finding relates to construction disturbance and species sensitivity is likely to vary according to disturbance type e.g. prized quarry species such as Teal may be more sensitive to disturbance originating from humans such as a dog walker (Pease et al., 2005, McLeod et al., 2013). Of the diving species at Abberton Reservoir, the decline in Tufted Duck was most significant with overwintering numbers significantly declining during the construction period, both at a site level and within the Central Section. This was shown to be specific to Abberton Reservoir, since the national trend was relatively stable (Appendix 4.4). Coot, Gadwall and Wigeon also showed declines within the Central Section which were associated with disturbance from raising of the B1026 causeway (see above). Despite significant declines reported for the Central Section during construction, the distribution of Wigeon shifted from the Main Section to the Central Section during those times when disturbance levels were at

their highest e.g. during concrete removal and shoreline re-profiling works in 2010 and 2011. In addition to a direct disturbance response, this result is likely due to a lack of undisturbed grazing habitat around the Main Section shorelines during re-profiling works. Other species demonstrating a spatial response away from high magnitude construction events were Coot, Tufted Duck, Pochard and Great Crested Grebe, conversely, Pochard and Teal showed habituation to the more constant, predictable construction activities.

Predictably, water depth was found to be an influential variable on the distribution of waterfowl at Abberton Reservoir; providing support for the influence of water depth on wetland ecology and waterfowl distribution (Hattori and Mae, 2001, Bancroft et al., 2002, Holm and Clausen, 2006, Cheek et al., 2014, Tavares et al., 2015, Schneider et al., 2017). Tufted Duck were found to be positively associated with areas of deeper water whilst the dabbling species (Gadwall, Teal and Wigeon) preferred shallow water close to the shoreline; as evidenced by Hurdle model and regression analysis (Chapter 5). Shoveler were also associated with shallow water but to a lesser extent than the other dabbling species and, at Abberton Reservoir, were found to have a sensitivity to wind and rain; a result attributed to weather disrupting their ability to filter feeding on zooplankton. One of the more surprising results was the association of diving species with high levels of macrophyte cover; usually associated with dabbling species and herbivores such as Mute Swan (Fox and Salmon, 1989, Benedict and Hepp, 2000, O'Hare et al., 2007, Sandsten and Klaassen, 2008). The positive relationship of diving species and macrophytes at Abberton Reservoir is attributed to aquatic vegetation providing habitat for high numbers of prey items such as molluscs and other invertebrates. A combination of aquatic vegetation, water depth and prey availability was the reason attributed to the notable discovery of Great Crested Grebe being spatially and statistically, positively associated with areas of the Main Section on the periphery of shallow and deep water. This has considerable implications for habitat management and restoration projects for this species and provides further support that successful wetlands are those with high structural diversity.

Efficacy of mitigation measures

Mitigation measures were incorporated into the Abberton Scheme through a phased construction programme, reservoir design and the creation of displacement habitat at the Western Section. The timing of construction activities considered to be the most disturbing to waterfowl i.e. concrete edge removal, was planned for April – September when waterfowl numbers were assessed (by the STIAA), to be at their lowest. Design features included maximising shallow water habitat through re-profiling activities and the inclusion of extensive lagoons. The displacement habitat was principally created to accommodate displaced Gadwall, Shoveler and Teal and was created in 2008; in advance of main construction works to allow it to sufficiently mature prior to its requirement. Success of design features and the construction programme was determined by results presented in Chapters 4 and 5, and efficacy of displacement habitat creation assessed in Chapter 6.

Numbers of waterfowl were significantly higher in the Main Section in years during construction compared to pre-construction and the increase was especially notable for the dabbling species, Gadwall, Shoveler and Teal. The increase for these species is attributed to removal of the concrete edge and re-profiling of the shorelines, which this study has shown to be highly beneficial as a design feature. Although some species showed sensitivity to construction disturbance, the timing of works is also considered a success due to waterfowl being able to fulfil their energetic requirements and avoid shoreline construction activities (the 200m 'zone of disturbance'), without relocating to a different site.

Some studies propose that disturbance should occur outside of the breeding season (Nolet et al., 2016) because disturbance during this time, can lead to lower reproduction rates and ultimately impact upon the population. For sites that are important to breeding waterfowl this is likely to be true. In the case of Abberton Reservoir however, substantially fewer waterfowl occur during the summer months compared to the winter months. Major construction activity during the winter therefore, is likely to have been highly detrimental. It is also likely that limiting major construction

activities to the winter months would have taken much longer and at additional cost, simply due to unfavourable ground conditions for earth moving machines. Ultimately this would have prolonged the duration the site was subject to construction disturbance and, extended the time taken for the shorelines and surrounding grassland habitat to establish. Furthermore, food resources (principally macrophytes and associated prey items), at Abberton Reservoir are more abundant during the summer months enabling waterfowl to balance energy budgets more readily than when food supplies are limited; or when waterfowl are in an incapacitated or reduced state, such as during moult or migration.

Mitigation for the Abberton Scheme was targeted in its approach, identifying three dabbling species as being most at risk from construction activities (Gadwall, Shoveler and Teal). Previous research has highlighted difficulties in designing successful mitigation habitat for a range of species (Atkinson, 2001b), particularly on a relatively small scale (Atkinson et al., 2004, Durell et al., 2005). The targeted approach adopted for the design and creation of displacement habitat at Abberton Reservoir, where shallow water and shoreline edges were maximized, is deemed to have been successful. Results from this research demonstrate that it was particularly beneficial for the target species, although increased use by a range of Abberton SPA species was observed following its creation. Previous authors suggest, that where wetlands provide roosting sites for waterfowl, densities tend to be higher (Hattori and Mae, 2001). The inclusion of islands was found to contribute to the success of the displacement habitat and was preferred by Gadwall, Shoveler and Wigeon, although overall, the habitat creation was of limited benefit to Wigeon; unlike the other dabbling species, numbers of Wigeon did not increase following creation of displacement habitat. This is likely to be a result of limited feeding opportunities and generally lower numbers of Wigeon observed at Abberton Reservoir for years during construction.

Assessments of mitigation habitat compliance have suggested that landscape context (near existing quality wetlands) was an important determinant of outcomes (Bosch and Matthews, 2017) and that

the typical five years monitoring period is not sufficient to determine success. This is because a new wetland may take 15 – 20 years or more to reach an equilibrium and a state of maturity (Stefanik and Mitsch, 2012). Immediate use of the displacement habitat at Abberton Reservoir, by a range of species, is attributed to its location and connectivity to an existing and mature body of water (the original Western Section and Layer brook), which contributed to providing sufficient food resources. Despite this, there is still evidence to suggest that conditions were not favourable for the diving species, including Great Crested Grebe. For the divers, Tufted Duck and Pochard, this was likely to be due to a lack of bivalves (a favoured prey item (Winfield and Winfield, 1994, Sekiya et al., 2000)), in combination with this species' preference for deeper water – conditions lacking in the new scrape areas. For Great Crested Grebe, the result is attributed to the relatively small size of the area and reduced water clarity (Chapter 6: Section 6.5.9).

Analysis carried out as part of this study concluded that the mitigation strategies incorporated into the Abberton Scheme were largely successful. However, some results were not predicted and therefore, somewhat surprising. The displacement habitat was beneficial to a range of Abberton Reservoir SPA species yet evidence presented here suggests the area was only used as intended, as displacement habitat, by Gadwall and to a lesser extent, Shoveler. The surprising element is that displacement originated from the Central Section and not, as anticipated, from the Main Section. Additionally, for Gadwall, there is evidence to suggest the area functioned as mitigation habitat during the overwintering period. This demonstrates that predicting the outcome of a project such as the Abberton Scheme and forecasting its effects, whilst essential and based on the best available knowledge at the time, is extremely difficult. Some may suggest that creation of the displacement habitat at the Western Section was neither necessary nor required, given disturbance impacts were largely mitigated for through project design. However, the success of these mitigation techniques was largely untested, certainly on a scale such as Abberton Reservoir and therefore the approach taken was targeted, experimental and precautionary. This research therefore reinforces the view that, if the science of mitigation and restoration is to be advanced, it is essential that an

experimental approach is taken and that sites are monitored adequately post-creation (Atkinson, 2001a). The successes and indeed failures of such projects can be used to further knowledge and increase predictive power; ultimately paving the way for effective and above all, beneficial 'net gain' mitigation and habitat creation.

In conclusion, results presented here suggest that efforts to reduce the effects of disturbance were largely successful and that at a site level, construction activity associated with the Abberton Scheme did not cause any deleterious effects to the integrity of the SPA. There is evidence to suggest that with appropriate consideration and evidence based planning, sites can tolerate manipulation or disturbance. However, some species were found to be affected to a greater extent than others, notably Tufted Duck and Wigeon, whilst significant benefits were reported for others such as Shoveler and Teal. The sensitivity of species was demonstrated to be influenced by site and habitat preferences with the size and habitat structure of the Main Section acting in itself, as a mitigating factor. Whilst site size and heterogeneity positively influenced the Main Section, the smaller more homogeneous Central Section saw pronounced disturbance effects and waterfowl displacement.

The lack of monitoring and, understandably, case studies such as Abberton Reservoir, poses difficulty in predictive ecology. With a few notable exceptions (Goss-Custard et al., 1991, Durell et al., 2005, West et al., 2005, Goss-Custard et al., 2006), the efficacy of mitigation measures or disturbance impacts are rarely predicted, quantified or reported. Findings reported as a result of this study have a number of both practical and theoretical applications, and have furthered knowledge of the effects of large scale construction on wetlands, with reference to disturbance and, maintaining internationally important populations of waterfowl. This is important as planning and decision making is often made in the absence of scientific rigor and on commonly held, but largely unsubstantiated views e.g. that waterfowl can habituate to more constant, low levels of construction disturbance. Here, for the first time, and at a large scale as far as a development goes, is a quantitative analysis of responses of target species to construction disturbance, the influence of

site environmental variables and assessment of incorporated mitigation measures. Findings support some commonly held beliefs whilst others bring something of a challenge to perceptions.

Scope for further work

A large amount of data was collated and analysed for this research and inevitably, as a result, a number of further questions were conceived, thus highlighting areas for potential further research, both at Abberton Reservoir and other large water bodies.

The analysis of spatial data is complicated by a phenomenon known as spatial autocorrelation which may violate the assumption of independence and bias parameter estimates (Dormann et al., 2007). Many waterfowl species and aggregations exhibit spatial autocorrelation and/or spatial dependency (spatial structuring linked to the environment), which may, as expected and of interest here, largely account for any observed spatial autocorrelation.

Spatial autocorrelation and zero-inflation are typically analysed separately by use of spatial statistics and zero-inflated models such as the Hurdle model. Methods to deal with spatial autocorrelation and zero-inflation are evolving and include zero-inflated generalised linear mixed models (ZIGLMMs). This class of models incorporates zero-inflation and generalised linear mixed modelling (GLMM) to allow for excess zeros, correlation between variables and random effects (Bolker et al., 2009, Zuur et al., 2009). Further work should seek to incorporate spatial autocorrelation into statistical modelling, advancing the predictability of waterfowl occurrence in response to, and in the presence of, disturbance. Spatial autocorrelation or environmental variables may not however, account for the natural flocking tendency of waterfowl i.e. ducks = more ducks. It is believed that any residual spatial autocorrelation issues associated with this research are of this nature.

Whilst evidence shows Abberton SPA species increased on the Main Section during construction, distributional changes attributed to construction disturbance were found. To investigate this further, behavioural changes relating to energy budgets i.e. time spent roosting and foraging, including

during the nocturnal period, would support and be a logical step from analyses presented here. To complement the research presented here, waterfowl data for a post-construction period and for other non-SPA species could be analysed and expanded to incorporate comparisons with other sites. This would contribute towards the development of a quantitative method to assess site sensitivity and susceptibility to development or disturbance. Additionally, the outputs would have applications towards devising adequate mitigation targets which can be monitored and used for compliance assessment. The approach to the Abberton Scheme and data used in this study, whilst unique in many aspects, can be used as a template for other sites with replicable results. Outputs can be used to assist in the development of guidelines, providing valuable reference material for site managers and researchers alike, and is applicable to water bodies of any size and geographical location worldwide.

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