

Ecological and anthropogenic constraints on waterbirds of the  
Forth Estuary: population and behavioural responses to  
disturbance

Ross G. Dwyer

Thesis submitted as candidature for  
the degree of Doctor of Philosophy

Centre for Ecology and Conservation  
University of Exeter  
May 2010

Ecological and anthropogenic constraints on waterbirds of the  
Forth Estuary: population and behavioural responses to  
disturbance

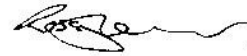
# Ross G. Dwyer

Submitted by Ross G. Dwyer, to the University of Exeter as a thesis for the degree of Doctor of Philosophy in Biological Sciences, May 2010.

This thesis is available for Library use on the understanding that it is copyright material and that no quotation from the thesis may be published without proper acknowledgement.

I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

## Abstract



Disturbance from engineering works is an increasing problem in terrestrial and marine ecosystems throughout the world. Many reported declines in population size, breeding success and body condition have been diagnosed as the result of anthropogenic disturbance, however little is known about the effect of long-term disturbance from large-scale engineering works. Understanding the mechanisms by which animals respond to anthropogenic activities is fundamental to explaining interactions, and resolving potential conflicts between humans and wildlife.

This thesis focuses on the factors affecting the habitat use and foraging decisions in wintering shorebirds and wildfowl. The first half of this thesis considers the direct and indirect impacts on waterbirds of a major engineering project in central Scotland; construction of the new Clackmannanshire Bridge at Kincardine-on-Forth. For individual bird species in close proximity to the bridge site, round-the-clock construction work had consequences ranging from neutral to considerably negative. Cormorant *Phalacrocorax carbo* declined in the area, probably as a result of the disturbance of an important low tide roost. Redshank *Tringa totanus*, previously abundant in the prey-rich areas adjacent to the construction site, were displaced into poorer areas for most of the construction period; where they may also have suffered from increased interference competition and elevated risk from raptorial predators.

Some positive effects of industrial development were also revealed; radio-transmitters combined with tilt-switch posture sensors indicate that Redshank were able to capitalise on the improved nocturnal visibility in areas around Grangemouth docks to assist with foraging and predator detection. Evidence is presented that birds switched foraging strategy (from sight to touch feeding) depending on ambient light levels; whereby artificial light was used in a similar manner to moonlight to assist with prey detection. Redshank also avoided riverine areas at night that were used frequently by day, probably in response to an elevated threat

from nocturnal predators. As the predator landscape changes from day into night, birds adopt different strategies to minimise the risk from nocturnal predators. It is clearly important, therefore, that information on nocturnal distributions is available to inform decisions on site management, especially where anthropogenic activity continues throughout the diel cycle.

Behavioural decisions were shown to vary widely within a species depending on individual state, metabolic demands and previous exposure to human disturbance. Prey resources were shown to change dramatically over the course of a winter. In response to this decline, the home range of Redshank contracted over a winter season. Similarly, animals responded less and took greater risks in response to experimental disturbance events later in the winter than earlier in the winter, and on days when the temperature was lower. This effect was strongest for individuals occupying heavily disturbed areas, which were possibly already compensating for lost feeding time and a negative energy balance. The results were consistent with the hypothesis that those individuals that respond most obviously to human disturbance were those least likely to suffer fitness consequences. This is the opposite from what is commonly assumed when behaviour is used as an index of disturbance impacts, most notably in the use of flush distance in the design of wildlife buffer zones.

In conclusion, this study demonstrated various negative impacts of disturbance, including local displacement, due to construction activity on overwintering waterbirds. It also revealed two key, but poorly understood, phenomena relating to mechanisms for coping with anthropogenic disturbance: routine utilisation of artificial light to extend night-time feeding opportunities amongst Redshank and an adaptive flexibility in escape responses across a range of species under varying conditions of risk.

## Acknowledgements

---

First of all I would like to thank my supervisor, David Bryant, for his endless help and encouragement, for nurturing a growing interest in ornithology and for commenting on every bit of text in this thesis. He was a constant source of guidance and inspiration throughout and I am most grateful for his confidence and patience while setting me up as an independent researcher. Stuart Bearhop was taken on as second supervisor at late notice and adopted me into his group as a PhD student, making me feel at home down in Cornwall. His open door policy was invaluable for discussion and advice on bird ecology, field techniques, and field equipment and presentation skills. He also commented on drafts of this thesis and never missed an opportunity to kick my ankles on the football pitch. Thanks to both my internal examiner, Annette Broderick, and my external examiner, John Quinn for agreeing to participate in the defence of my thesis. They made the viva a memorable experience and their comments greatly improved the content of this thesis.

It would not have been possible without the support and friendship from the Centre for Ecology and Conservation in Cornwall. Dave Hodgson entertained multiple questions on mixed models and encouraged the use of R for everything. Matt Witt taught me the rudiments of ArcGIS and always provided advice at short notice. Erika Newton, Will Pitchers, Iain Stott and Xav Harrison all helped decode a galaxy of programming errors in R and helped maintain my sanity in the office. Damo Smith, Tom Bodey, Rich Inger and Thor Veen also gave advice at various times throughout, whether it was in the office, out at sea or halfway up a sea cliff. Thanks to Jan Stipala and Anna Leonard for supplying essential field equipment and providing spares (usually through gritted teeth) when the first set were returned in pieces. I would like to thank John Calladine of BTO Scotland who, along with David Bryant, helped catch Common Redshank to colour ring and radio-tag as part of this study. Without John's expert help catching birds and Dave's help rigging nets and extracting birds (while often chest-deep icy water), this study would not have succeeded. Also, thanks to Sean Walls, Brian Cresswell and the Biotrack team for their expert advice on transmitter design and the production, repair and delivery of countless Yagi cables. Thanks to Dan Cox for his brief help and encouragement with midnight tracking, and to the great men of the AA who tolerated four burst tyres, two dead batteries and a flooded engine through all hours of the night in the most isolated of places. Thanks to Simon Young and David Chadwick of Jacobs Babcie for advice and communications on the bird monitoring chapter, and for letting me loose within the construction site armed with bins, scope and a hard-hat.

Finally, thanks to all my friends and family for their support throughout my PhD. Sophie Jamieson kindly provided the excellent shorebird illustrations, while Simon Campbell supplied bread and wine throughout the last few months of writing up; cheers! A special thanks to my Dad for his constant help throughout three years of fieldwork: sorting through mud samples, providing expert soldering advice, field trials on the Cromarty Firth and general "pigeon bothering". His patience and time were invaluable during what could have been, for him, a relaxing first year of retirement. Last of all, a very special thanks to Rebecca Jamieson: for all her love, support and patience over the last four years, for moving with me to Cornwall and for all her encouragement during those long, dark and cold nights out on the Forth estuary.

This work forms part of a study investigating the impacts of bridge construction on the internationally and nationally important bird populations in the vicinity of Kincardine-on-Forth. The monitoring program was commissioned by Transport Scotland and archival data supplied by Jacobs Group Ltd. I am grateful to all those who provided facilities at the

Department of Ecology and Evolutionary Biology at Glasgow University and at the Centre for Ecology and Conservation, University of Exeter Cornwall Campus.

# Contents

---

## List of figures

Figure 1.1: Map of the Forth estuary complex. The intertidal area is indicated by light shading and large urban areas on the Forth are indicated by dark shading. The area most likely to be disturbed by the construction of the new Clackmannanshire Bridge is indicated by the shaded box located between Stirling and Grangemouth. P.24

Figure 1.2: The engineering work in progress: i) construction of drilled pile foundations by the Seacore ® marine drilling station and ii) construction of the bridge deck, launched from the northern bank to minimize the disturbance to feeding and roosting grounds on the south side of the estuary. p.25

Figure 2.1: Map of Forth estuary showing sites, stations, shoreline and MLWS. p.40

Figure 2.2: Total invertebrate density (i) and biomass (g AFDW) (ii) in the Forth estuary study area. p.44

Figure 2.3: Species density (i) and biomass (g AFDW) (ii) in the Forth estuary study area in March 2008. p.45

Figure 2.4: Size-frequency histograms of i) *Hydrobia* (black), ii) *Macoma* (white) and iii) *Nereis* (grey) at all sample sites on the Forth estuary in March 2007/08. p.46

Figure 2.5: Mean *Hydrobia* density ( $\pm$ SE) at Kennet Pans (i) and Skinflats (ii) and mean *Hydrobia* biomass ( $\pm$ SE) at Kennet Pans (iii) and Skinflats (iv) from monthly sampling in winter 2007/08 and winter 2008/09. p.47

Figure 2.6: Mean *Macoma* density ( $\pm$ SE) at Kennet Pans (i) and Skinflats (ii) and mean *Macoma* biomass ( $\pm$ SE) at Kennet Pans (iii) and Skinflats (iv) from monthly sampling in winter 2007/08 and winter 2008/09. p.48

Figure 2.7: Mean *Nereis* density ( $\pm$ SE) at Kennet Pans (i) and Skinflats (ii) and mean *Nereis* biomass ( $\pm$ SE) at Kennet Pans (iii) and Skinflats (iv) from monthly sampling in winter 2007/08 and winter 2008/09. p.49

Figure 2.8: Species density (i) and biomass (g AFDW) (ii) at the Realignment site in March 2008 (first winter) and March 2009 (second winter). p.50

Figure 3.1: Map of study site showing count sector boundaries, the realignment site and the two bridges. p.66

Figure 3.2: (i) Annual trends in waterbird, wader and duck populations in the Kincardine-on-Forth study area between November 2003 (winter 1) and March 2009 (winter 6). (ii) Trends in waterbird, wader and duck populations before (Nov 2003-Mar 2006), during (Nov 2006-Mar 2008) and after bridge construction (Nov 2008-Mar 2009) from the study site. p.71

Figure 3.3: Before, during and after construction counts ( $\pm$ SE) of i) waterbirds and ii) waders within each count sector. p.72

Figure 3.4: Comparison of waterbird (i) and duck (ii) counts ( $\pm$ SE) across tidal stages (low, mid, high) during non-construction and construction winters in distant and bordering sectors. p.73

Figure 3.5: Comparison of Redshank counts ( $\pm$ SE) by individual count sector (i) and across early and late winter during non-construction and construction winters in distant and bordering sectors (ii). p.74

Figure 3.6: Comparison of Redshank (i) and Cormorant (ii) counts ( $\pm$ SE) across tidal stages (low, mid, high) during non-construction and construction winters in distant and bordering sectors. p.75

Figure 3.7: Time budget data for Redshank (i) and Shelduck (ii) inhabiting count sectors in winters during construction (07/08) and after construction (08/09) throughout late winter. p.77

Figure 3.8: i) Between-winter differences in the proportion of time Shelduck spent foraging in water compared to foraging on land in bordering and distant count sectors. ii) Model

predictions (lines) against actual values (dots) for those proportions of Shelduck feeding in water compared to those foraging on land across all tidal heights. p.78

Figure 4.1: The study area on the Forth estuary, Scotland: Location map with capture sites, radiotracking sites, Clackmannanshire Bridge, Kincardine Bridge and areas mentioned in text. p.96

Figure 4.2: A juvenile Common Redshank fitted with radio-transmitter and Darvic colour rings. p.97

Figure 4.3: Seasonal changes in size adjusted body mass (*BM'*) of juvenile and adult Redshank on the River Forth (2007-2009). p.98

Figure 4.4: Radio-tagged Redshank on the Forth estuary between November 2007 and March 2009. p.99

Figure 4.5: The radio-locations and estimated ranges of (i) Redshank ID 333, captured at Kennet Pans on 15/12/2009; (ii) Redshank ID 861, captured at Airth on 04/01/2009; (iii) Redshank ID 950, captured at north Skinflats on 17/11/2008; (iv) Redshank ID 905, captured at Skinflats lagoons on 02/12/2008. p.102

Figure 4.6: Relationship between i) home range and ii) core area size by capture date (days after November 1<sup>st</sup>) and the location where individuals were first captured. p.103

Figure 4.7: Comparison of (i) day vs. night home range and core area estimates ( $\pm$ SE) and (ii) early winter vs. late winter home range and core area estimates for Common Redshank overwintering on the Forth estuary. p.104

Figure 4.8: Plots of all fixes for selected individuals in 'early' (i) and 'late' (ii) winter, connected in sequence by lines to show course of winter habitat use. p.105

Figure 5.1: i) Distribution of transmitter-pulse rate for roosting and feeding birds. ii) Plots of pulse rate (ppm) collected from feeding birds over the proportion of time spent walking (Pwalking) and iii) the proportion of time spent pecking (Ppecking). p.126

Figure 5.2: Radio-tagged Redshank present between November 2008 and March 2009. p.126

Figure 5.3: i) Locations of all 13 birds in study calculated by triangulation using LOAS software (points). Light intensity layer is composed of 1 km<sup>2</sup> pixels and is a colour representation of satellite measurements of artificial light taken at night by the U.S. Air Force DMSP in 2000. p.128

Figure 5.4: i) The proportion of Redshank feeding diurnally and nocturnally by season. ii) The proportion of Redshank feeding diurnally and nocturnally by tidal regime. p.129

Figure 5.5: The proportion of Redshank feeding in study area by day (i) and by night (ii) and the interaction between moonlight and cloud cover. p.130

Figure 5.6: Map of diurnal (i) and nocturnal (ii) Redshank habitat use on the Forth estuary. p.131

Figure 5.7: Comparison of mean pulse rate for individual birds by day and by night. p.132

Figure 5.8: Mean transmitter-pulse rate for birds feeding during the day (i) and during the night (ii) and the interaction between moonlight and cloud cover. p.133

Figure 6.1: The Forth estuary study area, showing tidal mudflats (light shading) and the five sites selected for disturbance experiments. p.152

Figure 6.2: Relationship between (i) Redshank log-transformed flight-initiation distances (*FID*) and (i) *site-disturbance score* and *season*; and (ii) Redshank log-transformed flight initiation distances (*FID*) and *site-disturbance score* and *temperature*. p.156

Figure 6.3: (i) Relationship between Shelduck log-transformed *FAD* and *disturbance score* and *temperature*. ii) Mean log-transformed fly-away distances (*FAD*) for Shelduck by *season*. p.157

Figure 7.1: Annual indices for Redshank (i), Curlew (ii), Oystercatcher (iii), Teal (iv), Shelduck (v) and Cormorant (iv) in BTO Inner Forth WeBS counts vs. the TTTCs reported in **chapter 3**. p.176



Figure 7.2: Diurnal and nocturnal spring tide (>5m) roosts used by radio-tagged Redshank. p.182

## **List of tables**

---

Table 2.1: Preferred size classes of prey selected by waterbird species. p.37

Table 2.2: Names and physical characteristics of study sites. p.41

Table 2.3: Equations used to predict prey biomass) from measurements of prey size (x). p.42

Table 3.1: Names, physical characteristics and disturbance frequency of individual count sectors. p.68

Table 6.1: Number of visits, observed recreational disturbances at each site and disturbance scoring classification for each site. p.152

Table 6.2: The number of flushes for each species at each site ( $n \geq 7$ ) and their respective mean flight-initiation distance (*FID*) score. p.155

Table 7.1: Mean flight initiation distances (*FID*) and recommended set-back distances (*RS*) between wintering waterbirds and an intruder walking directly towards the flock, for waterbirds on the Forth estuary. p.183