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Changes in Survival and Recruitment of Oystercatchers *Haemotopus ostralegus* at Traeth Lafan, North Wales, in Relation to Shellfish Exploitation

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CONTENTS

Page No.

List of Tables

Page No.

List of Figures

Page No.

List of Appendices

Page No.

EXECUTIVE SUMMARY

Traeth Lafan is an area of intertidal sand and mud flats located in Conwy Bay, to the eastern end of the Menai Straits. It is notified as a Special Protection Area (SPA) for its use as a severe weather refuge for Oystercatchers. Numbers of wintering Oystercatchers declined from approximately 5,000 birds in 1983/1984 to a low of 1,500-2,000 in 1990/1991. Since then there was an increase to a peak of 6,000-7,500 birds in 2001/2002.

The area also supports a small hand-gathering cockle fishery. Since 1980, exploitation has generally been low, except in the autumns of 1989, 1990 and 1993 when suction dredging took place for cockles on part of the area. Since the 1990s, only 2-3 people have fished the hand fishery area, removing 2-3 tonnes of cockles per year. However in 2004, 80 migrant workers fished the hand-gathering area and removed an estimated 100 tonnes. Due to the concern about the amount of cockles taken the beds were subsequently closed.

Data on cockle stocks are limited. From 1994-1996, stocks were low but increased and remained high between 1997 and 2000. Mussel culture has rapidly increased since 1990 and landings from one operation increased from <1,000 tonnes in 1990 to 10,000 tonnes in 2003/2004.

Adult Oystercatcher survival rates and the proportion of juveniles in the flocks were calculated to explain the changes in the population. The proportion of juveniles in the flocks was on average 0.22 ± 0.02 and was lowest during the period of dredging and significantly higher before and after. No food-related mass mortality events were observed at Traeth Lafan and average survival was 90.7% using ringed birds recovered dead and reported to the British and Irish Ringing Scheme. In dredging years there was a strong indication that survival was 6% lower than normal. This pattern was observed in the analysis of birds recovered dead, but was not found in the analysis of live recaptures. This was probably due to the irregular nature of catching. Recruitment, rather than major changes in mortality, was the main driver of population change.

Adult Oystercatchers were in poorer body condition during the dredging period, being on average 5.6 and 17.2g heavier before and after the dredging. Although small (a maximum of 3.5% of winter body weight) these differences were significant.

During the period of dredging cockle stocks were low, Oystercatchers suffered higher mortality, juvenile recruitment was lower and birds were in a slightly poorer condition. There was no evidence from ringing recoveries that there were any large-scale movements of birds away from Traeth Lafan to other areas during this period.

The increase in mussel farming has provided new feeding opportunities for Oystercatchers and the rapid increase in the number of birds from the mid 1990s is likely to be due to birds exploiting these new food resources. The natural mussel beds and commercial leys will provide a 'buffer', which can compensate for years when cockle stocks are low.

This study has shown that experimental suction dredging of cockles had negative effects on three life history parameters of Oystercatchers. It is therefore predicted that the introduction of regular suction dredging would cause a decline in Oystercatcher fitness, leading to reduced wintering populations. Although mussel stocks have been high for the last 5-10 years, much of the available mussel stocks are on commercial leys and thus outside the control of external agencies. If mussel stocks were to decline then it would be expected that Oystercatchers would be poorly conditioned and suffer increased mortality in years when there is a low availability of cockles, due either to fishing or natural population fluctuations. Thus, to ensure a healthy Oystercatcher population, sufficient stocks of both cockles and mussels are necessary.

CRYNODEB

1. Mae Traeth Lafan yn ardal o dywod a llaid rhynglanwol ym Mae Conwy, ar ochr ddwyreiniol y Fenai. Mae’r ardal wedi cael ei dynodi yn Ardal Gwarchod Arbennig oherwydd ei bod yn lloches i biod môr yn ystod tywydd garw. Mae nifer y piod môr sydd yn gaeafu yma wedi dirywio o ryw 5,000 o adar yn 1983/1984 i isafswm o 1,500-2,000 yn 1990/1991. Ers hynny bu cynnydd at uchafswm o 6,000-7,500 o adar yn 2001/2002.

2. Mae’r ardal hefyd yn cynnal ychydig o weithgaredd hel cocos â llaw. Ers 1980 nid oes llawer o gocos, ar y cyfan, wedi cael eu cymryd o’r safle, ag eithrio yn ystod tymhorau hydref 1989, 1990 a 1993 pan gafodd cocos eu carthu o’r safle gyda pheiriannau sugno. Ers y 1990au dim ond 2-3 berson sydd wedi bod yn pysgota yn yr ardal sydd wedi ei neilltuo ar gyfer pysgota â llaw, gan gymryd 2-3 tunnell o gocos bob blwyddyn.Ond yn ystod 2004 bu 80 o weithwyr tymhorol yn pysgota yn yr ardal hon ac amcangyfrifwyd eu bod wedi hel 100 tunnell yno. Oherwydd y gofid ynglŷn â chyfanswm y cocos a gasglwyd bryd hynny fe gafodd y gwelyau cocos eu cau.

3. Ychydig o ddata sydd i gael ar y stoc o gocos. Rhwng 1994-1996, roedd y stoc yn isel ond fe gynyddodd wedyn, a pharhaodd i fod yn uchel rhwng 1997 a 2000. Mae’r stoc o gregyn gleision wedi tyfu yn gyflym ers 1990 a gwelwyd cynnydd sylweddol yn y cyfanswm pwysau a ddaliwyd gan un fenter bysgota, o <1,000 tunnell yn 1990 i 10,000 tunnell yn 2003/4.

4. Aed ati i amcangyfrif cyfradd goroesi’r oedolion a chyfran yr adar ifanc mewn heidiau o biod môr, er mwyn egluro’r newidiadau yn y boblogaeth. Roedd y gyfran o adar ifanc yn yr heidiau yn 0.22 ± 0.02, ar gyfartaledd; roedd y gyfran ar ei hisaf yn ystod y cyfnodau pan oedd carthu yn digwydd, ac yn arwyddocaol uwch cyn ac ar ôl y cyfnodau hyn. Ni chafodd unrhyw dystiolaeth o farwolaethau torfol, o ganlyniad i brinder bwyd, eu cofnodi ar Draeth Lafan ac roedd y gyfradd goroesi, ar gyfartaledd, yn 90.7%, o ddefnyddio’r cofnodion o fodrwyau adar marw a gafodd eu hanfon at Gynllun Modrwyo Prydain ac Iwerddon. Yn ystod y blynyddoedd pan fu carthu yn digwydd roedd arwydd clir bod y gyfradd goroesi yn 6% yn is na’r arferol. Gwelwyd y patrwm yma mewn dadansoddiadau o briodoleddau adar a ganfuwyd yn farw, ond ni chafwyd yr un patrwm wrth ddadansoddi priodoleddau adar a gafodd eu hail-ddal yn fyw. Mae’n debyg mai natur anghyson y dal oedd yn gyfrifol am y gwahaniaeth hwn. Recriwtio, yn hytrach na newidiadau mawr mewn marwoldeb, oedd yn bennaf gyfrifol am y newidiadau poblogaeth.

5. Roedd cyflwr cyrff oedolion piod môr yn waeth yn ystod y cyfnod carthu. Ar gyfartaledd, roeddent yn 5.6g a 17.2g yn drymach cyn ac ar ôl y carthu. Er bod y newidiadau hyn yn fach, (ar y mwyaf yn 3.5% o gyfanswm pwysau’r corff) roeddent yn arwyddocaol.

6. Yn ystod y cyfnod carthu roedd y stoc o gocos yn isel. Roedd mwy o biod môr yn marw yn ystod y cyfnod hwn, roedd llai o adar ifanc yn cael eu recriwtio i’r boblogaeth ac roedd cyflwr yr adar ychydig yn waeth. Nid oedd unrhyw dystiolaeth, o edrych ar fodrwyau adar a ddaliwyd mewn lleoedd gwahanol, bod unrhyw symudiadau mawr o adar i ffwrdd o Draeth Lafan i ardaloedd eraill yn ystod y cyfnod hwn.

7. Mae’r cynnydd mewn ffermio cregyn gleision wedi creu cyfleoedd bwydo newydd i biod môr ac mae’r cynnydd cyflym yn nifer yr adar o ganol y 1990au yn debygol o fod yn adlewyrchu defnydd yr adar o’r cyflenwad bwyd newydd yma. Bydd y gwelyâu naturiol o gregyn gleision a’r gwelyâu masnachol yn ffynhonnell o fwyd wrth gefn yn ystod blynyddoedd pan fydd y stoc o gocos yn isel.

8. Mae’r astudiaeth yma wedi dangos bod arbrawf i garthu cocos drwy sugno wedi cael effaith negyddol ar dri pharamedr sy’n dylanwadu ar fywyd piod môr. Rhagwelir felly, pe byddai carthu drwy sugno yn digwydd yn rheolaidd ar y safle hwn, y byddai lefel ffitrwydd y piod môr yn dirywio, gan arwain at leihad ym maint y poblogaethau sy’n gaeafu yma. Er bod y stoc o gregyn gleision wedi bod yn uchel yma dros y 5-10 mlynedd diwethaf, mae llawer o’r cregyn gleision o fewn gwelyâu masnachol ac felly y tu hwnt i reolaeth asiantaethau allanol. Pe byddai’r stoc o gregyn gleision yn dirywio, mae’n debygol wedyn y byddai cyflwr piod môr yn dirywio ac y byddai eu niferoedd yn gostwng yn fwy o ganlyniad i farwolaeth yn ystod y blynyddoedd hynny pan nad oes fawr o gocos ar gael, un ai oherwydd gweithgaredd pysgota neu oherwydd marwolaethau naturiol ymhlith y boblogaeth. Felly er mwyn sicrhau poblogaeth iach o biod môr, rhaid cael stoc ddigonol o gocos a chregyn gleision.

1. INTRODUCTION

1.1 Project Background

Traeth Lafan is an area of intertidal sand and mud flats located in Conwy Bay, to the eastern end of the Menai Straits. Traeth Lafan is notified as a Special Protection Area (SPA) for its use as a severe weather refuge for oystercatchers. The SCAN ringing group has ringing data on the Traeth Lafan oystercatchers going back over 25 years. It is a valuable resource, collected by volunteers, which has not yet been analysed. The data will be used by this study for two aims: firstly to help us understand the changing oystercatcher populations at Traeth Lafan, relating this where possible to past management activities; and secondly to input survival data into the Centre for Ecology and Hydrology (CEH) study to model the shellfish requirements for the Traeth Lafan birds; a study which will inform future consents for shell fishery on the site.

Oystercatcher populations are declining in the west of the United Kingdom, but increasing in the north-east. During the 1970s and 80s the population at Traeth Lafan declined more than at other sites in this area of the country; however the population has since stabilised and is showing a slight increase (Austin *et al.* 2004). There may be many causes for these changes. It could relate to events or changes at their breeding grounds or at their over-wintering ground, Traeth Lafan. The study will investigate the adult survival rates and juvenile recruitment of the Traeth Lafan oystercatchers, relating historic trends and changes to significant on-site activities such as cockle-dredging and commercial mussel farming. Data for Traeth Lafan will also be compared to other sites.

The second driver for the study is that CEH is modelling the shellfish requirements of the Traeth Lafan birds, in order to inform future applications for cockle dredging and other shellfishery activities. Without information on juvenile recruitment and adult survival, assumptions have to be entered into the model, making it less accurate. The actual data will be used to validate the model. The model will be the most powerful tool yet to inform CCW on the likely impacts of applications for large-scale shellfishing and will be an important part of appropriate assessment processes for the SPA.

1.2 The Importance of the Traeth Lafan SPA for Oystercatchers

Traeth Lafan was designated an SPA on the basis of providing a severe weather refuge for birds on the Dee estuary (SPA review). The 5-year mean number (1991/2 - 1995/6) of Oystercatchers was 4,931 individuals representing at least 0.5% of the wintering Europe & Northern/Western Africa population. Most of the Oystercatchers that winter on the west coast of the UK are from breeding areas in northern England, Scotland, Iceland, the Faeroes and to a lesser extent Norway. Oystercatchers do not reach sexual maturity until three years old and young birds, once they have reached the wintering grounds tend to stay there, or near there, in the following summers until they reach sexual maturity (Sitters 2002). Birds breeding in northern England and Scotland tend to migrate down the west coast to winter on west coast estuaries and a few cross the Channel and have been recovered in France and Spain. Traeth Lafan is therefore important not only for adult and juvenile summering and wintering Oystercatchers, but also birds passing through to areas further south.

Oystercatchers predominantly take shellfish, although feeding on worms is common amongst juveniles. Once adult, however, few birds take worms and concentrate on blue mussels *Mytilus edulis* and cockles *Cerastoderma edule.* In periods of food shortage they may take other sources of food, particularly *Macoma* and other clams (Zwarts *et al.* 1996). Birds may also spend the high tide period ‘topping up’ on invertebrates in surrounding agricultural or amenity grassland if such habitat is available (Goss-Custard *et al.* 1994).

1.3 The Fishery

Traeth Lafan is an extensive area of mud and sandflats to the north-east of the Menai Straits covering approximately 25 km^2, with up to 5km of tidal flats exposed at low tide. The area currently supports extensive cockle beds, which are exploited by shellfish-eating birds and by fishermen in a small hand-raking cockle fishery. The density of cockles has been such that it has not supported a larger fishery (Allen 1995), with the exception of limited and experimental commercial suction dredging on three occasions in the late 1980s and early 1990s.

During the ten years prior to 2004, the public beds were fished intermittently by 2-3 people on 3-4 occasions over the period in which the beds were opened. Landing data from the public hand-gathering fishery are very limited and figures are probably unreliable as there is no requirement to report landings. During this period, however, probably no more than 2-3 tonnes of cockles per year were harvested (NWNWSFC pers. comm.). In 2004 up to 80 migrant workers fished the beds and approximately 100 tonnes were taken from the bed prior to closure. The bed remains closed.

Prior to this, commercial cockle harvesting on Traeth Lafan was not a viable concern (Eagle *et al.* 1974). Exploitation of the public bed increased during the early 1980s due to increased competition in other more established fisheries, such as the Solway Firth (Allen 1995), but the returns were still borderline in economic terms. Experimental suction dredging took place in three periods on part of Lafan Sands. These periods were 1 June and 31 August 1989, 1 September and 30 November 1990 and, after a break of two winters, a final period in the autumn of 1993. The fishery was closed to further dredging events in December 1994. An impact survey was carried out after the second dredging event to determine the impact of the dredging on the macroinvertebrate faunas of Traeth Lafan (Allen 1995). Invertebrate densities and diversity were generally low and there were only slight differences in the non-target macro invertebrates between dredged and non-dredged areas. The lack of an adequate pre-dredging baseline and the six week interval between cessation of dredging and start of monitoring meant that it was very difficult to draw any conclusions about the impacts on dredging on non-target species. Sandy substrates are a feature of disturbed areas and autumn storms had removed the evidence of dredging tracks by the time the surveys commenced.

Changes were, however, detected in the size of the cockle stock. Recruitment and post winter survival was reasonable in summer 1993 (Cook 1993) and 700 tonnes were estimated to be available. During the authorised period 1,100 tonnes were taken as fishermen were able to exploit sub-tidal stocks which were not accounted for in the previous estimate. As would be expected just after the dredging, cockle numbers were much reduced in the exploited areas (20-38 m^{-2} in dredged areas and 140m^{-2} in non-dredged areas) so adult mortality was significantly increased. Poor recruitment followed the dredging event and numbers on the control plots fell 12 months after the dredging event.

1.4 Changes in Cockle and Mussel Populations at, and in Areas Surrounding, Traeth Lafan

As Traeth Lafan is not a major commercial fishery, surveys of cockle stocks have only been carried out intermittently. Data collected by NWNWSFC and collated by Andy West from CEH Dorset, are presented in Table 1. Since the last of the dredging events in the 1993/1994 winter, cockle densities were low (<20 m^{-2}) until a major recruitment of one-year-old cockles in 1997/1998, due to a spatfall the previous year (for densities see Table 1). These persisted until at least 2000/2001 after which no further suitable data are available.

Mussel culture has also increased dramatically in areas around Bangor. Landings form commercial growers in the eastern part of the Menai Straits have shown an exponential rise from <1,000 tonnes between 1980/1981 and 1990/1991 to over 7,000-10,000 tonnes in 2001/2002 to 2004/2005 (Figure 2). Between 1999-2001, up to 2,000 Oystercatchers consumed 242 metric tonnes of these mussels on one (out of three) natural beds and three (out of five) leys and thus the number of mussel feeding Oystercatchers is likely to be much higher (Caldow *et al.* 2004). This approximated to 19% of the landings at a commercial cost of £133,000. As a result of this predation, growers have adopted new practices, which involve laying seed mussels (15-20mm) upshore, where losses to Oystercatchers should be minimal. They are then moved progressively downshore so that, in the final year before harvest, they occupy the lowest areas which will only be exposed on spring tides, thus reducing the amount of time they are available to the birds.

1.5 Project Aims

The project had six major aims:

1. Model adult survival rates
2. Model juvenile recruitment into the population
3. Examine changes in body weight of birds over the last 25 years

4. Comparison of the above with other sites where similar data is available
5. Information-gathering on significant management changes and events during the period, particularly with regard to shellfishery.
6. Examine whether any significant events (e.g. shellfishery changes) were reflected in population changes

2. METHODS

2.1 Changes in Bird Numbers

Comprehensive counts of waterbirds have been made approximately monthly between September and March in the Traeth Lafan / Menai Straits and north-east Anglesey area since 1983/1984 as part of the Birds of the Estuary Enquiry (BoEE) or its successor, the Wetland Bird Survey (WeBS). Full details of these national waterbird monitoring surveys can be found in Musgrove *et al.* 2001.

Between 1983/1984 and 1992/1993 only a single count figure was available for the stretch of shoreline ranging from Penmon, across the tubular bridge to Llanfairfechan saltings for each month but from 1993, this area was split into a number of sectors and separate counts made within these. Given the single figure available for the early years it is difficult to determine the quality of the counts but is the best available information.

2.2 Age Ratios

Birds were caught regularly by the SCAN Ringing Group at three different sites between 1980 and 2003 (Table 2). To estimate the proportion of juveniles across catches, we used the individual-based index developed by Clark *et al.* (2004). The proportion of juvenile birds in each catch (1 August – 31 March), and associated error, was expressed using the 'events/trials' syntax, i.e. 'number of juveniles/total number of birds' and modelled as a function of winter and site factors using a Generalised Linear Model (GENMOD procedure in SAS), with a logit link function and a binomial error distribution. As individual birds are often not independent (i.e. birds exhibit non-random flocking) there was a greater degree of variability in the data than would be expected from a simple binomial error distribution. Consequently, a variance inflation factor was employed (using the PSCALE option in GENMOD) to account for this over-dispersion. This had no effect on the mean parameter estimates, but increased the error estimates (and hence confidence limits) appropriately. Estimates were also produced for the periods April to July (for over-summering birds) and for October to March (true winter proportions). These are presented in Appendix 2.

2.3 Survival

The aim of the survival analysis was twofold. First to determine annual estimates of survival, and trends over time, of Oystercatchers from a site that is not a major commercial fishery. Second, to estimate survival in the three years when trial mechanical suction dredging occurred to determine whether mortality increased.

Annual survival estimates and reporting rates (the probability of a marked dead bird being reported) were estimated using the computer package MARK (White & Burnham 1999) based on birds which were trapped and ringed by the SCAN Ringing Group at sites adjacent to Traeth Lafan (Figure 1). Between 1980 and 2003, members of the SCAN ringing group caught and ringed approximately 9,000 adult oystercatchers in these areas (Table 2). Birds were caught whilst roosting over the high tide period using cannon nets. Prior to 1980, catching effort was patchy and data from these years were excluded. The majority of birds were caught at three sites (Ogwen, Wig and Llanfairfechan) and catches have been made each year from at least one of these three sites (Table 2). Birds have also been caught at other sites along the coast from Penmon Point to Bangor, notably Penmon Quarry Beach, and to the east of Traeth Lafan to Rhos-on-Sea. However these catches have been sporadic and thus not suitable for an analysis of survival that uses live retraps.

On capture, birds were ringed, aged using criteria in Prater *et al.* (1977), measured, weighed and released. For the purposes of this analysis, birds were divided into two age classes - juveniles if they were in their first year of life (taken from 1 July to the following 30 June) and adults, if they were greater than one-year-old. We have restricted survival estimation to adults because of the low proportion of juveniles caught, the low recovery rate and the issue that became apparent in the adult survival analysis of much lower recovery rates in the year following ringing.

Several different approaches can be taken to determine survival. As the catching effort is not consistent at each site in each year it is necessary to use survival models to estimate both the survival and reporting rates from year to year and this can be performed using the recovery of dead birds or the recapture of birds previously ringed. There are strengths and weaknesses with each approach, but before the survival modelling proceeds, it is necessary to determine whether the data conform to certain assumptions that are used in the modelling process. One of the most crucial assumptions is that all birds have a similar probability of being recovered dead or recaught.

2.3.1 Goodness of fit and model selection

For analyses using live recaptures, goodness of fit tests were carried out in the program U-CARE (Choquet *et al.* 2003). If the tests showed significant deviation from the model assumptions then the variance inflation factor $\hat{c}$ was used to adjust the variance associated with the survival and reporting rate parameters, and hence influence model selection. The variable $\hat{c}$ was calculated using the bootstrap method in MARK for both live recapture and dead recovery analyses.

For the survival models, the need for inclusion of age- or time-dependent survival and reporting rates was determined by using the Akaike information criterion (AIC) as a basis for model selection, as recommended by Burnham and Anderson (1998). The AIC was used as it selects the most parsimonious model which best explains the data, but uses the smallest number of parameters. Difference of >2 are generally considered 'significant' but AIC is not a formal testing procedure but is rather a measure of the strength of support to any given model. When the overdispersion parameter $\hat{c}$ is used, the AIC becomes the quasi-AIC (QAIC) and is used in selecting models. For formal testing, likelihood ratio tests were used to test the significance of the differences in deviance between nested models.

2.3.2 Estimating survival using birds recovered dead

Only a small proportion of the ringed population is reported as dead to the BTO ringing office each year. However, one advantage of this method is that, on a local scale, the reporting rate tends to suffer less bias than in live-recapture analyses as the opportunity to for a bird to be reported is not limited to the one or two catching events in a given year.

Ringing and recovery years ran from 1 July to 30 June. Ideally for survival analyses, the capture of all individuals would take place within a very short time period. However given the small number of birds caught and recovered, it was considered best to maximize the numbers of birds in the analysis. We also included recoveries away from Traeth Lafan in the survival estimation, on the grounds that factors operating in North Wales could cause birds to move away and die elsewhere, or the condition in which birds leave Traeth Lafan may affect subsequent survival.

In this study catching attempts at the three sites (Ogwen, Wig, Llanfairfechan) did not take place at each site every year, but it was aimed to catch at each roost every second year. Catching attempts may be biased due to disturbance, or due to the differential distribution of birds within flocks. Lower status birds (generally juveniles or younger birds) tend to occupy the edges of flocks and are less likely to leave the beach during disturbance events, thus there tends to be more variation in reporting rate using live, rather than dead, recaptures.

Recovery analyses can also show biases and heterogeneity in recoveries. To offset the impact of these, it is possible to measure the over dispersion in the recapture histories (a value called $\hat{c}$) and use this to adjust the error associated with the parameter estimates. The value of $\hat{c}$ was bootstrapped using the fully time dependent model and found to be 2.75. This value was used when selecting the final models. The reporting rate in the year following capture is often lower than subsequently, a common phenomenon in mark-recapture analyses of this type. This was explicitly tested and found to be required.

2.3.3 Estimating survival using live recaptures

There are several problems particularly associated with using live recaptures to estimate survival in waders. First, cannon-netting is a labour and time-intensive process and so there tend to be a smaller number of large catches. In any one year there may only be one or two catches available for use at a particular site, and in the current situation, there may have only been samples of birds caught at one or two of the three main catching sites.

Mark-recapture type analyses require that each bird has an equal probability of recapture in each time period. If birds mix at random between catches and sites then this is not an issue. However, waders may be faithful to a particular roost site. If, for instance, a catch was made only at Llanfairfechan in one year and then at all three sites in the following year, then if there is any degree of site fidelity, the recapture probability of birds ringed the previous year at Llanfairfechan is likely to be different at all three sites. It would therefore inappropriate to lump catches and use the retraps between these three sites.

To investigate this problem further, we identified the first ringing sites for each individual bird from 1980 onwards and for each year calculated the expected and observed proportions of retraps at each of the three sites in subsequent years. The expected proportions were simply based on the cumulative numbers of birds first ringed in each site since 1980 (assuming a 90% annual survival rate) and assumed that, across years, birds redistributed themselves evenly between the three sites. So, if for example, a cumulative total of 1000 birds had been ringed at each of the sites then, we would expect 33.3% of the retraps to have been originally ringed at each site.

For each winter, where more than 10 retraps were caught in each site, we calculated the proportion of birds that had been first-ringed at each of the three sites and the percentage difference from the expected value. These were averaged across years and results presented in Table 3. These clearly show that movement between sites is not random. For example, retraps from Llanfairfechan were 75% fewer than expected in catches at the Ogwen roost (6 km away), a pattern also seen at Wig (at a distance of 3.5 km). Movements were more frequent than expected between Ogwen and Wig (2.5 km apart) indicating a high degree of interchange, although the effect was larger when considering movements from Ogwen to Wig.

It is therefore inappropriate to use the dataset as whole given the issue of heterogenetity in retrap rates and goodness of fit testing, performed using the computer package U-CARE (Choquet *et al.* 2003), supported this. When birds from all three sites were included, assumptions of the Cormack Jolly Seber model were violated (χ^2=156,17, df=77, P<0.0001). Breaking down the test further, there was an excess of transients i.e. birds ringed and not seen again (Log-Odds-Statistic for transience = 3.94, one-sided test P<0.0001).

However, it may be appropriate to consider each site individually (i.e. just include birds caught and retrapped at that site) and average survival rates across sites, or group two sites together. When split down into the three component data sets, transience was, again, an issue for each site. As transience was an issue, the appropriate value of $\hat{c}$ (the variance inflating factor) was used in selecting the best models.

Splitting down the data reduces the power to detect changes in survival, as the many recapture events between sites were lost. The numbers of birds in the split datasets was too low to detect changes in survival following cockle-dredging events and it was really only possible to calculate annual survival. To determine whether there were site differences we split the data only into two groups based on Table 3 which showed that birds originally ringed at Llanfairfechan were much less likely to be caught at either Ogwen or Wig. We therefore split the data in two, one set with just Llanfairfechan birds and one containing birds from the other two sites.

2.4 Weights of Birds Before, During and After the Suction Dredging Periods

On the majority of catches, birds were weighed and weight data are available for 6,742 birds caught between 1980 and 2004. During the period of suction dredging, catches were sporadic so, rather than analyse weights by year, we grouped the data into periods *before*, *during* and *after* the dredging events (see Table 4 for sample sizes and time period definition).

Weights were modelled using the GENMOD procedure in SAS, as a function of a factor variable, *month*, a three level *timing* factor variable (before during and after dredging). Normal errors were specified. This effectively looked to see whether there were differences in the mean monthly weight between the three periods.

3. RESULTS

3.1 Changes in Bird Numbers

The average numbers of Oystercatchers counted between Penmon and Llanfairfechan have fluctuated between c. 1,500 to 6,000 (Figures 1 & 3). These show a broadly similar pattern to the maximum counts, which peaked at 7,831 birds in the 2001/2002 winter. The number of birds declined from 1983 to a low in the 1990/1991 winter and have shown a steady recovery since then, reaching a pre-decline level by the late 1990s.

Cockle dredging took place in the autumns of 1989, 1990 and 1993. A decline in numbers was apparent before the first dredging event but, even so, the average count of birds the following winter was the lowest on record. The number of birds has steadily recovered since then.

3.2 Age Ratios

There were sufficient data to calculate the proportion of juveniles for all but one year. As with other similar studies of oystercatchers, juveniles were recorded each winter and the average proportion was 0.22 ± 0.02 SE, n=22 years), ranging between 0.06 and 0.44 (Figure 4). As well as differences between years, there were also differences between site, with Wig having the lowest proportion of juveniles and the Ogwen the highest.

When broken down into periods before any dredging (<1989), during (1989/1990-1993/1994) and after (>1993/1994), some clear patterns emerge. The model was rerun with the site variable but the winter factor was replaced with a three factor variable relating to the timing of dredging (before 1989/1990, 1989/1990-1994/1995 and post 1994/1995). The proportion of juveniles in the catches was lowest during the period in which dredging occurred (0.16 ± 0.037 SE), intermediate prior to the dredging (0.19 ± 0.034) and highest after the dredging events (0.28 ± 0.032). These figures show a similar pattern to the changes in numbers. This timing variable was highly significant (χ^2 = 201, df=2, P<0.0001). Post hoc tests indicated the recruitment was significantly higher, both before (χ^2 = 12.83, df=1, P<0.0001) and after (χ^2 = 135.68, df=1, P<0.0001) the period in which dredging occurred.

3.3 Survival

3.3.1 Estimating survival using birds recovered dead

Using an over dispersion factor of 2.75, four models with time-dependent and/or constant reporting and survival rates were fitted (Models 4, 6, 8 and 9 in Table 5). Model 4, with a constant reporting rate was a much better fit compared with the other three with a drop in QAICc of 31.05 indicating that both survival and reporting rates have varied little since 1980. We took this best fit model and, to test whether there was an age effect in reporting rate, a separate reporting rate was given for the first year after ringing (Model 2). This proved to be a strong effect (a drop in QAIC of 10.27) and age-dependent reporting rates were retained in the model selection procedure.

With this as model base we tested whether the incidence of dredging in a particular year had an effect on survival. We allowed survival in each of the three dredging years to be consistent (Model 1) or different (Model 3). Model 1 proved to be a better fit, than a model with constant survival but the difference between these models was only close to significant (LRT: χ^2 = 3.09, df=1, P=0.078). The survival estimate for non-dredging years was 92.1% but 86.1% in dredging years, a drop of 6%. Although the best fit model does indicate that there may be an effect of mechanical cockle dredging on survival, the support for it is not equivocal. Overall, average survival was 90.7% (95%CI: 84.7% - 94.5%)

3.3.2 Estimating survival using live recaptures

Survival models were constructed for two different dataset, Ogwen & Wig birds, Llanfairfechan birds (Table 6). The appropriate values of $\hat{c}$ were bootstrapped and model selection was based on the QAIC value.

As with most live recapture analyses, the inclusion of time-dependent reporting rates in the model is essential as catching effort often changes markedly between years. For both the Ogwen and Wig, and Llanfairfechan datasets there was little evidence of an effect of dredging. The inclusion of dredging in the first set of models (Table 6a) showed that the inclusion of the dredging parameter worsened model fit and in the second only improved it by 0.07, thus, in reality, making the models equivalent.

As with the dead recovery analyses, the best fit model was found to be one with constant survival across time. Various groupings including periods before, during and after dredging were tried but none improved model fit significantly. Average survival was remarkably similar for the two sub-divided datasets at 88.9% and 88.4% (Table 7), slightly lower than that estimated by the dead recovery analyses (90.7%).

3.4 Weight Changes

Oystercatchers at Traeth Lafan showed a pattern of slight weight gain from an average of 520g in July to 550g in November, a slight drop during December and January and then a period of high weight gain prior to departing for the breeding grounds in February and March (Figure 5). The peak weight of 597g was reached in March.

Juveniles tended to show a similar, but not as extreme, pattern to adults but were on average 16g lighter from June to December. After December, this gap increased to 47.5g in January, 67.1g in February and 81.9g in March. Juveniles tend to spend their second year on, or close to the wintering areas and so do not need to put on weight to migrate back to their, more northerly, breeding areas.

Weights of both juveniles and adults were lower during the period in which suction dredging occurred. For both age class models, the timing variable (before, during or after dredging) was significant (adults: χ^2= 84.19, df=2, P<0.0001; juveniles: χ^2= 9.39, df=2, P<0.01). Adults were on average 5.6g and 17.2 g higher in the period before and after the dredging. Juveniles showed a similar pattern and were on average 10.7g and 11.1 g higher before and after the dredging. These consistent results, between both age classes and season, indicate strong evidence for a change in body condition during the dredging period.

4. DISCUSSION

The evidence presented in this report strongly suggests that conditions on Traeth Lafan were poor for Oystercatchers in the late 1980s and early 1990s. Although correlative, there is a strong indication that this coincided with the experimental period of suction dredging and low cockle stocks. During the period of dredging, adult Oystercatcher survival rates were 6% lower than in other years, the recruitment of juveniles and the body mass of birds was significantly lower. Overall, annual survival rates (90.7% using dead recoveries and 88.4 and 88.9% using live recoveries) were similar to another study on the Wash, which were found to be 89.0% (which used dead recoveries).

4.1 What Has Driven Changes in the Population on the Traeth Lafan SPA?

The survival models that used dead recoveries indicated that, during the dredging periods, the survival of Oystercatchers was on average 86.1%, 6% lower than in other years, which averaged 92.1%. Juvenile recruitment, however, varied much more and, since the period of dredging, on average 28% of the catches were juvenile birds. This is a very high recruitment rate and, if sustained, the population of Oystercatcher will continue to increase. We were not able to determine the juvenile survival rates with confidence. We did attempt to construct dead recovery models, but were not confident there was sufficient data to give a reliable estimate. However, all indications were that juvenile survival was similar to adults, similar to a finding from the study on the Wash (Atkinson *et al.* 2003). This was further backed up by an analysis of the probability of an individual bird being recaptured in future years, based on its age. If, as might be expected, juveniles suffered higher mortality than adults, then for any given year, we would expect to catch a lower proportion of birds ringed as juveniles in future years. In fact, there was no significant difference between the probability of subsequent recapture of birds originally ringed as adults or juveniles.

Since the dredging events, the population has increased at approximately 10% per year. The high proportion of juveniles in the catches post dredging is likely to have caused this. However in all three periods, the percentage of juveniles has ‘outstripped’ the percentage of adults dying. Therefore we would have expected the population to have increased, rather than show a dip in the late 1980s. There could be several reasons for this. First, our assumption that juveniles have a higher mortality than adults may be wrong. On the Exe estuary on average 1.4% of adults and 5.2% of juveniles die over the course of the winter. The remainder of the annual mortality comes during the course of migration to and from the breeding areas or whilst breeding (Durell *et al.* 2000). On the Wash, Atkinson *et al.* (2003) found a similar situation, where approximately 2% of adult birds died in winter and 8% in summer. If the situation is similar on Traeth Lafan then, with juveniles being present all year round and not migrating, mortality is not likely to greatly exceed that of adults.

If the counts show a correct pattern then there could be a significant emigration of birds out of Traeth Lafan. This is unlikely as the average ‘survival’ rate of birds in the live recapture analyses was not too dissimilar to that found in the dead recovery analyses. Survival, in this case, refers to all birds that leave the system permanently, either through death or permanent emigration. Another explanation, that could be tested, is that there is different distribution of adults and juveniles in the flocks surrounding Traeth Lafan. This would be expected as the extent of mussel culture expands. Mussels are a preferred food for Oystercatcher and higher status birds will dominate the mussel beds leaving juveniles to forage in poorer quality areas.

In summary, recruitment has varied over time but survival has remained relatively constant and the patterns in the proportion of juveniles indicate that it is this that has driven the recent increase in population. The apparent excess of juveniles and dip in the population needs to be explained. It is possible that there has been a redistribution of adult birds on to the increasingly large mussel beds, adults roosting close to these and thus increasing the proportion of juveniles roosting near the cockle beds. There is good evidence of a large increase in the number of birds roosting near the mussel beds (Figure 6). If these were adults from areas surrounding Traeth Lafan, then it would be expected that juveniles would take their place. This would make our estimates of the proportion of juveniles unreliable when considering the population that uses Traeth Lafan as a whole. The proportion of juveniles is likely to be a useful index, but not an absolute measure of juvenile recruitment.

4.2 Why Has Large Mortality Amongst Oystercatchers Not Occurred in North Wales?

The situation at Traeth Lafan is difficult to diagnose because the data on shellfish stocks is very limited and it is not possible to directly relate shellfish stocks to bird survival. During the dredging period, large amounts of cockles were removed from part of the cockle beds and, in 1993, fishermen were able to take more cockles than were thought to be harvestable (Cook 1991). Surveys in 1994-1996 indicated that cockle densities were low (Table 1), but no large mortality events were observed amongst the Oystercatchers. During this period, the extent of commercial mussel farming rapidly increased thus providing an additional food source for the Oystercatchers. It is very likely that it is this that has caused the recent increase in the Oystercatcher population. Indeed, since the late 1990s, the rate of growth in the Oystercatcher population has been much greater in the Beaumaris to Bangor area, compared with the Bangor to Llanfairfechan stretch of coast (Figure 6) and numbers in the latter area have been rather static. The main mussel growing areas are in the Menai Straits and correspond with the areas in which roosting Oystercatchers have increased most.

The live recapture analysis did not find any changes in survival during years in which dredging took place but the dead recovery analysis did. This apparent mismatch is most likely explained by the problems associated with live-recapture analyses. Unfortunately catching effort was lowest during the period *prior to* and during the time in which dredging took place (only 4 birds were caught during one of the three dredging winters). This has meant that there would be very little power to detect changes in survival, unless the changes were very large. Dead recovery analyses rely on ringed birds being reported back to the British and Irish Ringing Scheme. If ringed birds die and are washed up on the beach, they are potentially available to be recorded 365 days a year, rather than on the 1-2 catching occasions per winter as in live recaptures. The recovery effort is also likely to be less biased towards one roost or another and so, for the analyses, it is likely that birds from roosts that are only occasionally caught could be included. To ensure consistency between the live and dead recapture analyses we only used birds that had been caught at Ogwen, Wig and Llanfairfechan. We did explore analyses using birds caught at all roosts surrounding Traeth Lafan and they gave similar results suggesting that there was no consistent bias.

4.3 Impact of Shellfishing and Changes in Food Supply on Shellfish-eating Birds. What Evidence is there From Elsewhere that Birds Can Respond?

Fishing for shellfish has long been blamed for the large declines in shellfish-eating birds. Numbers of Oystercatchers, Red Knot *Calidris canutus* and Eider *Somateria molissima* had been reduced in the Dutch part of the Wadden Sea. Coupled with declines in numbers, major mortality of Eiders occurred and all available data indicate that this was due to food shortage (Camphuysen *et al.* 2002).

It is not until recently that the scientific backing for this has emerged for the impact of the commercial shellfishing (Verhulst *et al.* 2004). In the Wadden Sea, cockles recruit on average once every 6 years and during the fishing season an average of 25% of the cockle bed in open areas was touched by a cockle dredger each year (Ens *et al.* 2004). This major fishing mortality led to large protected areas being set up for shellfish-eating birds (26%-31% of the total area of tidal flats in the Dutch Wadden Sea). However, a recent study has shown that there was no redistribution of birds from unprotected areas, where cockle fishing mortality was high, to the protected areas. The birds in the unprotected areas had a 43% higher mortality, less shellfish in their diet and a lower body condition (Verhulst *et al.* 2004). The corresponding figure in this study is a 76% increase in annual mortality. It is very likely that the suction-dredging fishery explained some of the 40% decline in Oystercatcher numbers in the Wadden Sea.

This seeming inability to move away from areas with poor food supplies, may seem somewhat surprising as, during severe weather, Oystercatcher in the Wadden Sea are know to perform large-scale movements to warmer climates. Large numbers of birds move into north-eastern France where they tend to suffer high hunting mortality (Camphuysen *et al.* 1996). In the Wash, however, a situation similar to the Verhulst *et al.* study was observed. Between 1980 and 1990, the cockle and mussel stocks collapsed due to a long run of poor shellfish recruitment following high fishing rates in the 1980s (Bannister 1998, 1999). Over the same period, Oystercatchers declined from 40,000 to 11,000 birds. As food supplies reached record lows, instead of moving elsewhere, large numbers of birds died in three winters (Atkinson *et al.* 2003) and winter (October to March) mortality was 5-13 times that in normal years. Birds switched to alternative food sources such as worms and other invertebrates on agricultural and amenity grassland (which is in short supply around the

Wash). This is atypical behaviour for Wash birds but typical of the behaviour exhibited in the Netherlands during periods of food shortage (Smit *et al.* 1998).

4.4 What Lessons About Shellfish Management Have Been Learnt Elsewhere?

Cockle populations tend to undergo large fluctuations and, in the Wadden Sea, there is on average, a successful recruitment every six years (Ens *et al.* 2004). Thus, in some years cockle stocks are very low, and birds are forced to feed on alternative prey sources, such as clams or mussels. Mussel populations tend to fluctuate much less, as they form stable beds, which can persist for centuries. Again, good mussel recruitment only takes place sporadically, on average every four years in the Wadden Sea (Ens *et al.* 2004). Settling mussel spat need a rough surface to survive well and an existing mussel bed is ideal as the spat are able to 'hide' in the interstices of the mussel bed and grow. Bottom dredging breaks up existing mussel beds and degrades them to such an extent that they disappear. Removal of the mussel beds thus makes successful establishment of spat much more difficult, so once mussel beds have been fished out, new ones may take a long time to establish.

In both the Wash and Wadden Sea, mussels are therefore the key to successful management of birds. Alternative prey such as *Macoma*, polychaete worms and clams are taken during periods of cockle shortage but mussels are a preferred food and mussel availability will offset the reduction in cockle stocks. In both the Wadden Sea and the Wash, the natural beds were fished out and thus in poor cockle year, mussels could not act as a 'buffer' and Oystercatcher mortality increased.

4.5 Would an Active Cockle Fishery on Traeth Lafan be Likely to Cause Damage in Future?

The profitability of the cockle fishery on Traeth Lafan has always been on the edge of what would be considered economical but this will change as the price of cockles changes. The recent banning of suction dredging in the Netherlands may increase demand on cockle fisheries elsewhere. Suction dredging can exploit very low densities of cockles and in some years this activity would be profitable. However, major concerns have been raised about the ecological damage that suction dredging causes (Piersma *et al.* 2001). Bottom dredging causes changes in sediments that may take years to recover and also cause long-term damage to macroinvertebrate infauna and features such as mussel beds or clusters of tube-living polychaetes. Depending on the hydrological conditions and the extent of dredging, recovery times can be slow (Collie *et al.* 2000). Due in part to these concerns, suction dredging has not been allowed in the Traeth Lafan Special Protection Area (SPA) and cockle harvesting has, therefore, been confined to a small hand-raking fishery. This is limited in extent and is unlikely to cause major ecological problems if it remained at levels similar to those prior to 2003. The sudden influx of 80+ cockle fishermen in 2004 led to an increased harvest of cockles and presumably increased disturbance to the birds. Hand raking takes place at low water, and can cause disturbance to feeding birds as well as reducing food supplies.

It is clear from the available data that declines in the food available to Oystercatchers can lead to increased mortality and reduced juvenile recruitment and thus it would be predicted that any major extension of the hand-raking fishery or the reintroduction of suction dredging would cause declines at this site. Continuation of the monitoring of the Oystercatcher populations by counting and catching will be important to detect any changes in the health of the Oystercatcher population.

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Table 1. Mean densities (number m^{-2}) of 1+ring (i.e. >1 year old) cockles from surveys on Traeth Lafan. These would be of a size suitable for Oystercatchers. Source: West, pers. Comm..

Year	Month	Mean cockle density (1+ rings)	SE	N
1994	Feb	16.58	3.68	38
1994	Nov	14.55	3.13	44
1995	Oct	12.36	2.39	55
1996	Sept	13.76	1.53	52
1997	Oct	106.00	24.15	20
1998	Oct	44.17	5.29	48
2000	Oct	62.83	22.33	27

Table 2. The number of adult and juvenile Oystercatchers caught each year and the number of catches at three sites surrounding Traeth Lafan from 1980/1981 to 2003/2004. Years run from 1 July to 30 June. **Bold** indicated time periods in which mechanical suction-dredging events took place. OGW = Ogwen, WIG = Wig, LLA = Llanfairfechan.

	Numbers of birds caught (Ads / Juvs)				Number of catches		
Winter	OGW	WIG	LLA	TOTAL	OGW	WIG	LLA
1980	115/6	696/75	0/0	892	1	3	
1981	142/14	120/91	21/13	401	1	2	3
1982	46/19	322/64	26/5	482	1	5	3
1983	307/58	0/0	0/0	365	3		
1984	0/0	0/0	311/54	365			1
1985	28/3	113/10	338/78	570	1	1	2
1986	0/0	0/0	0/0	0			
1987	0/0	69/44	0/0	113		1	
1988	0/0	0/0	216/19	235			1
1989	**4/0**	**0/0**	**0/0**	**4**	**1**		
1990	**222/20**	**0/0**	**202/34**	**478**	**1**		**1**
1991	48/6	0/0	64/30	148	1		1
1992	291/32	325/45	0/0	693	1	1	
1993	**11/6**	**0/0**	**308/66**	**391**	**1**		**1**
1994	35/35	68/46	0/0	184	1	2	
1995	67/108	221/21	39/15	471	1	1	1
1996	180/55	185/42	1/3	466	2	1	1
1997	103/108	0/0	255/47	513	1		2
1998	0/3	182/24	128/92	429	1	2	3
1999	1/1	0/0	173/41	216	2		2
2000	12/60	221/46	14/5	358	1	2	1
2001	11/4	307/129	1/1	453	1	2	2
2002	11/7	33/6	282/121	460	2	1	1
2003	0/0	417/27	0/0	444		1	

Table 3. Summary of the movements of ringed birds between sites. The figures are the observed difference (expressed as percentage difference) from the expected number of retraps caught at each site, based on where they were first caught, e.g. in catches of birds at Ogwen, there were 74.5% fewer retraps from Llanfairfechan, than would be expected if birds redistributed at random.

			First ringing site		
		Number ringed	Ogwen	Wig	Llanfairfechan
	Ogwen	1652	-11.1	27.3	-74.5
Retrap site	Wig	4390	64.5	-9.2	-38.9
	Llanfairfechan	2426	2.9	-18.2	22.2

Table 4. Numbers of Oystercatchers (adults/juveniles) weighed at sites surrounding Traeth Lafan in each month since 1980. Note no birds have been caught and weighed in May. **Bold** represents the catches which were considered to have taken place during the period of dredging.

Calendar Year	Jan	Feb	Mar	Apr	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1980	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	200/15
1981	110/12	0/0	12/5	0/0	0/0	0/0	0/0	115/78	0/0	4/17	0/0
1982	12/3	141/14	9/4	28/30	138/174	0/0	0/0	48/19	30/5	31/18	0/0
1983	93/12	10/5	190/28	132/42	58/34	0/0	116/11	90/9	0/0	0/0	0/0
1984	11/17	0/0	0/0	10/13	0/0	35/14	0/0	0/0	0/0	119/20	0/0
1985	0/0	0/0	0/0	0/0	0/0	0/0	137/13	0/0	168/10	0/0	0/0
1986	0/0	0/0	0/0	0/0	45/74	0/0	0/0	0/0	0/0	0/0	0/0
1987	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	68/42	0/0
1989	0/0	113/7	0/0	0/0	61/81	**0/0**	**0/0**	**0/0**	**0/0**	**0/0**	**0/0**
1990	**0/0**	**0/0**	**0/0**	**0/0**	**0/0**	**0/0**	**0/0**	**0/0**	**190/28**	**0/0**	**0/0**
1991	**0/0**	**0/0**	**0/0**	**9/0**	**0/0**	**0/0**	**108/36**	**0/0**	**0/0**	**0/0**	**0/0**
1992	**0/0**	**0/0**	**0/0**	**0/0**	**0/0**	**0/0**	**0/0**	**0/0**	**90/12**	**0/0**	**0/0**
1993	**121/6**	**0/0**	**0/0**	**0/0**	**0/0**	**0/0**	**0/0**	**0/0**	**76/120**	**0/0**	**0/0**
1994	**0/0**	**95/26**	**0/0**	**0/0**	0/0	0/0	35/35	0/0	17/7	0/0	0/0
1995	0/0	0/0	36/22	0/0	0/0	33/17	39/15	0/0	62/96	0/0	0/0
1996	0/0	0/0	158/15	0/0	0/0	0/0	0/0	245/85	0/0	0/0	0/0
1997	1/3	102/12	0/0	0/0	0/0	0/0	0/0	0/0	148/82	0/0	0/0
1998	0/0	0/0	0/0	0/0	0/0	50/26	0/0	103/69	0/0	0/0	0/0
1999	169/18	0/0	0/0	0/0	0/0	41/22	0/0	0/0	0/1	150/40	0/0
2000	0/0	1/0	0/0	0/0	0/0	0/0	0/0	11/60	148/35	15/2	0/0
2001	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	90/47	0/1	108/48
2002	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	11/4	0/0
2003	0/0	0/3	32/5	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0
2004	2/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	51/0	37/0	0/0

Table 5. The model selection process for survival models using dead recoveries of Oystercatchers. *S* = Survival and *r* = recovery probability. *t* = time dependent model; . = constant; *dredging* = the winters 1989/1990, 1991/1992 and 1993/1994 set to have different survival rates; age is where the recovery probability in the year after capture is set to be different (but constant) and constant thereafter.

	Model	QAICc	Delta QAICc	N	Deviance
1	$S_{(dredging)}\ r_{(age)}$	869.155	0	4	91.296
2	$S_{(.)}\ r_{(age)}$	870.244	1.09	3	94.388
3	$S_{(dredging\ 3\ separate\ years)}\ r_{(age)}$	871.978	2.82	6	90.112
4	$S_{(.)}\ r_{(.)}$	880.515	11.36	2	106.661
5	$S_{(t)}\ r_{(age)}$	904.127	34.97	24	86.071
6	$S_{(t)}\ r_{(.)}$	911.563	42.41	23	95.524
7	$S_{(t)}\ r_{(age)}$	911.563	42.41	23	95.524
8	$S_{(.)}\ r_{(t)}$	911.878	42.72	21	99.869
9	$S_{(t)}\ r_{(t)}$	912.871	43.72	26	90.78

Table 6. The model selection process for survival models using live recaptures of Oystercatchers. *Phi* = Survival and *p* = reporting probability. *t* = time dependent model; . = constant; *dredging* = the winters 1989/1990, 1991/1992 and 1993/1994 set to have different survival rates.

(a) Ogwen and Wig ($\hat{c}$ =2.02)	QAICc	dQAICc	n	QDev
$Phi_{(.)}\ p_{(t)}$	2420.98	0	24	236.11
$Phi_{(.,dredging)}\ p_{(t)}$	2422.99	2.01	25	236.1
$Phi_{(t)}\ p_{(t)}$	2457.19	36.21	46	227.73
$Phi_{(t)}\ p_{(.)}$	2594.15	173.17	24	409.28
$Phi_{(.)}\ p_{(.)}$	2601.17	180.19	2	460.52

(b) Llanfairfechan only ($\hat{c}$ = 2.9)	QAICc	dQAICc	n	QDev
$Phi_{(.,dredging)}\ p_{(t)}$	737.93	0	24	65.01
$Phi_{(.)}\ p_{(t)}$	738	0.07	23	67.12
$Phi_{(t)}\ p_{(t)}$	774.63	36.7	44	60.43
$Phi_{(.)}\ p_{(.)}$	789.66	51.73	2	161.29
$Phi_{(t)}\ p_{(.)}$	812.28	74.35	23	141.41

Table 7. Survival estimates from live recapture analyses using data from Ogwen & Wig, Llanfairfechan and all three sites.

Dataset	Mean survival (95% CIs)
Averaging across 3 sites	0.889 (0.864-0.909)
Llanfairfechan only	0.884 (0.809-0.932)
Ogwen & Wig	0.885 (0.857-0.908)

Figure 1. Location of the main wader catching areas within the study site and the number of birds caught in each site by the SCAN Ringing Group. Site codes are described in Appendix 1. Counts of birds have taken place from Penmon Point (PEQ), to Menai Bridge and then westwards to Llanfairfechan. All of the birds roosting at these sites have the potential to exploit the cockle beds on Traeth Lafan.

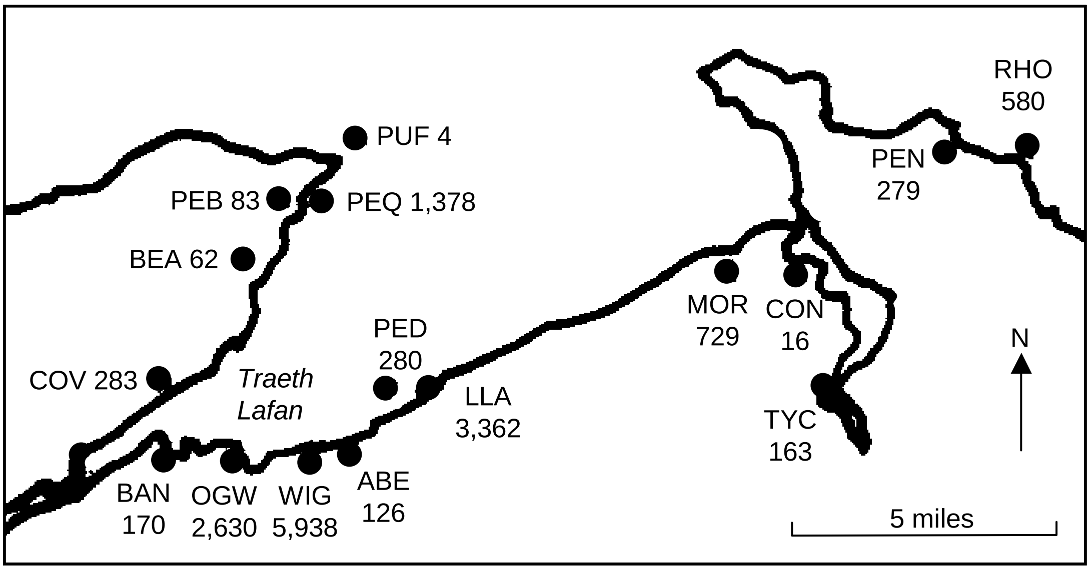


Figure 2. Changes in the amount of mussels harvested in the Menai Strait. Figures represent the combined annual landings of all commercial mussel farming companies with beds at the eastern end of the Menai Strait from 1980 onwards. Figures refer to the autumn and following winter (i.e. 1980=1980/1981). Data from Kim Mold (in litt.).

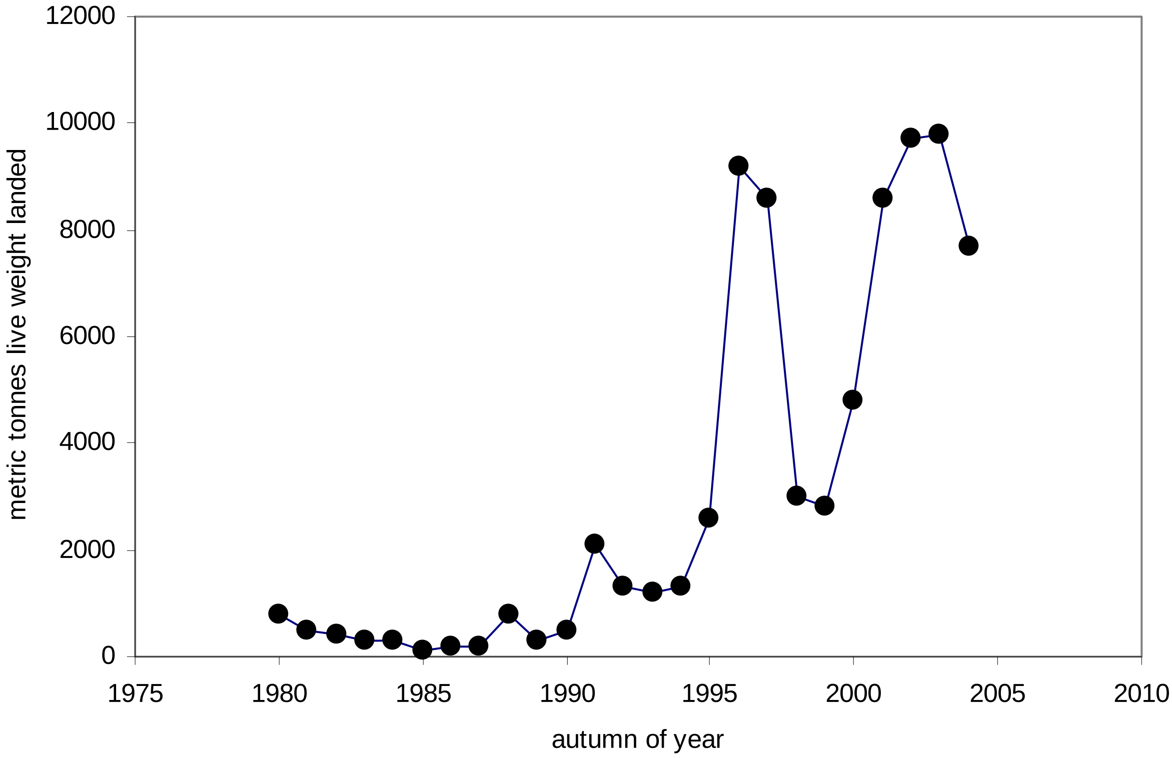


Figure 3. Changes in the numbers of Oystercatchers counted at roost sites surrounding Traeth Lafan from the 1983 winter (October 1983 – March 1984) onwards. Clear bars represent the peak count during the period and the filled bars, the average count. Cockle suction dredging events took place in the autumn of 1989, 1990 and 1993.

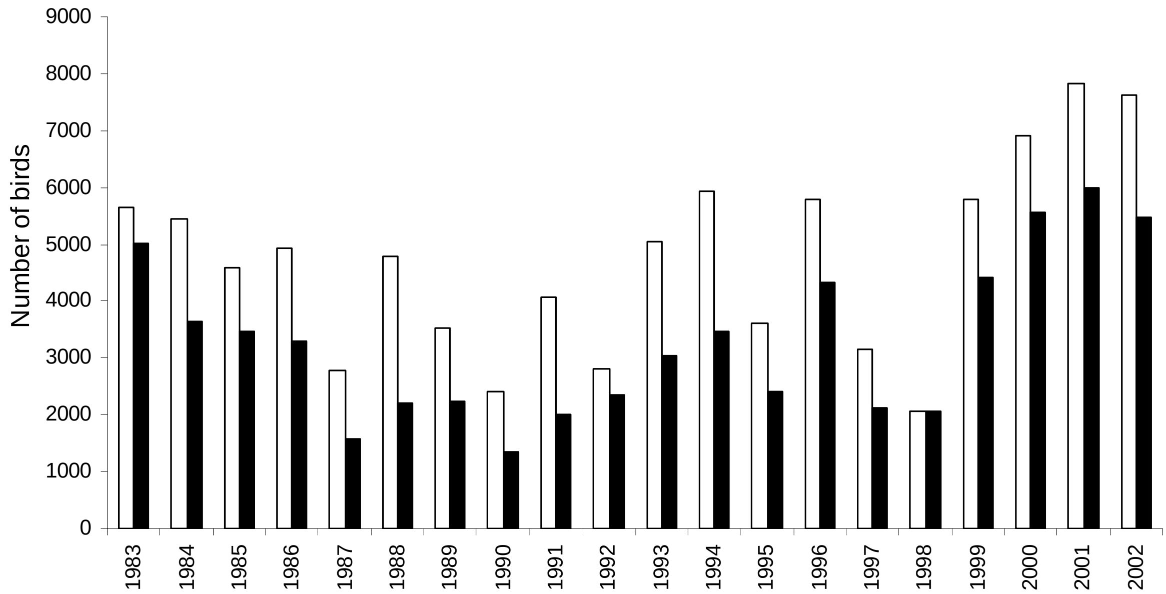


Figure 4. Changes in the proportion of juvenile Oystercatchers in the catches at Ogwen, Wig and Llanfairfechan.

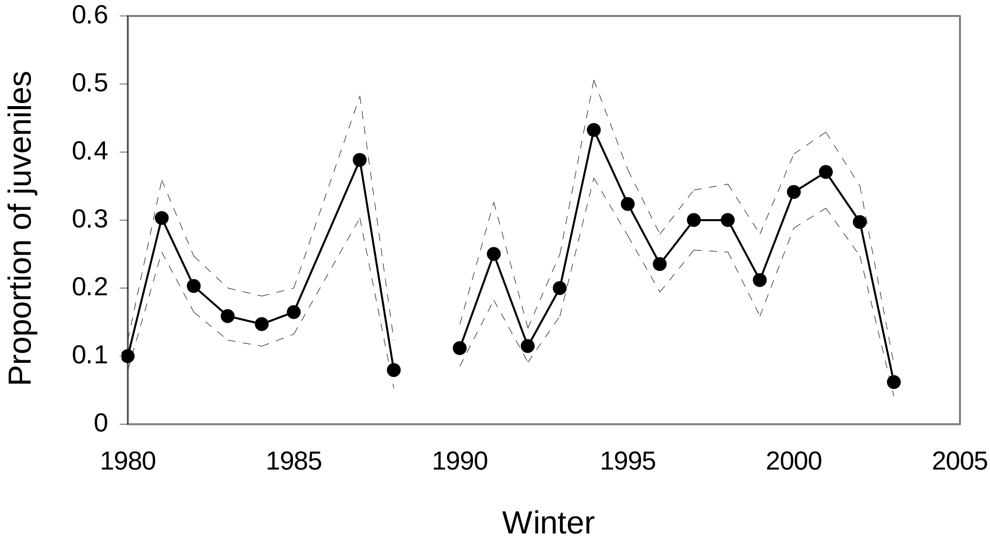


Figure 5. Changes in the mean mass (+/- SE) of adult and juvenile Oystercatchers at Traeth Lafan in relation to month. Sample sizes are in Table 4.

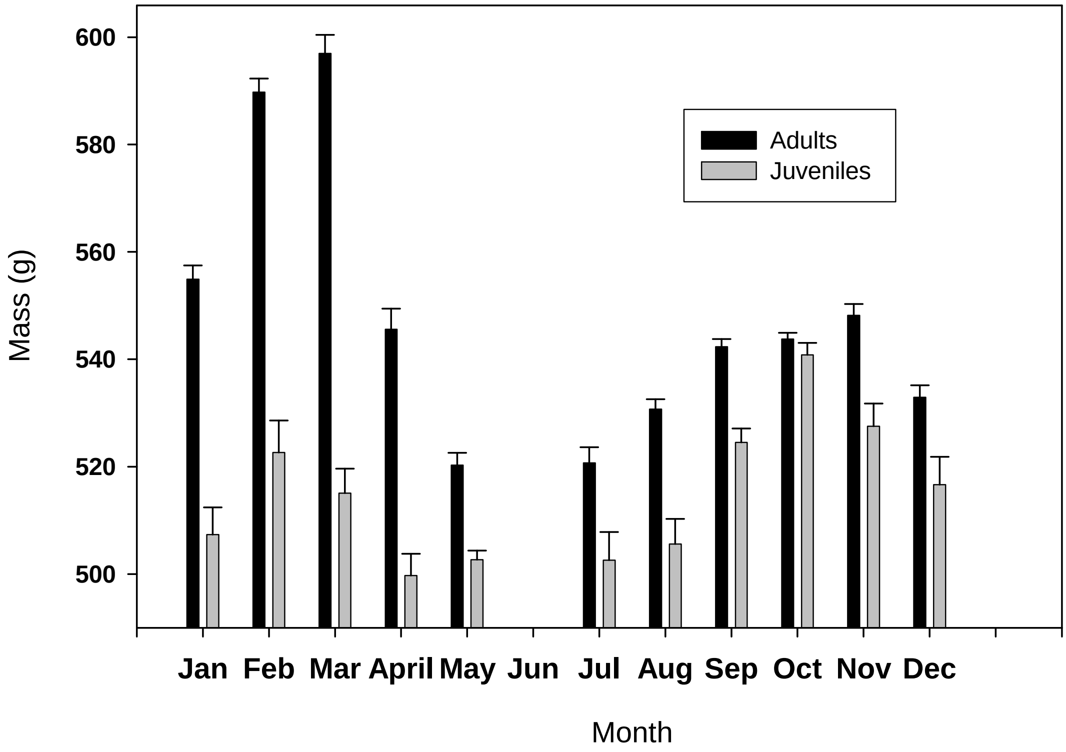
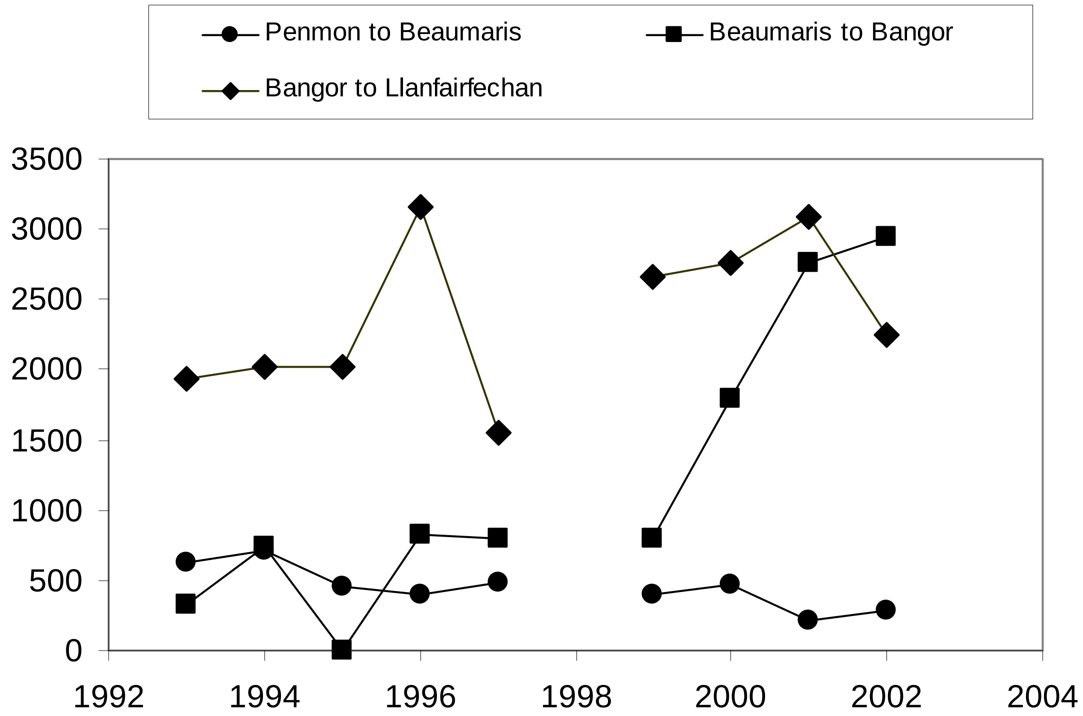


Figure 6. Changes in the average numbers of Oystercatchers recorded between October and January along three stretches of coastline in the areas surrounding Traeth Lafan. Years refer to winters, i.e. 1993 = October 1993 to March 1994.



Appendix 1 Location and site names of the sites where Oystercatchers have been caught by the SCAN Ringing Group. County code: GBGB = Gwynedd, GBCW = Clwyd and GBAN = Anglesey.

Site Code	Latitude	Longitude	County code	Site Name	National Grid Reference
OGW	53°14'N	04°05'W	GBGD	Ogwen Estuary	SH6072
WIG	53°14'N	04°03'W	GBGD	Wig	SH6372
LLA	53°15'N	04°00'W	GBGD	Llanfairfechan	SH6674
ABE	53°14'N	04°02'W	GBGD	Aber	SH6473
BAN	53°14'N	04°07'W	GBGD	Bangor Harbour	SH5972
BEA	53°17'N	04°05'W	GBAN	Beaumaris	SH6177
COV	53°15'N	04°07'W	GBAN	Pen-y-Parc, Beaumaris	SH5874
MOR	53°17'N	03°52'W	GBGD	Conwy Morfa	SH7578
PEB	53°18'N	04°04'W	GBAN	Penmon Beach	SH6279
PED	53°15'N	04°01'W	GBGD	Pentre Du	SH6573
PEN	53°19'N	03°46'W	GBGD	Penrhyn Bay	SH8281
PEQ	53°18'N	04°03'W	GBAN	Penmon Quarry beach	SH6380
PUF	53°19'N	04°02'W	GBAN	Puffin Island	SH6582
RHO	53°19N	03°44'W	GBCW	Rhos-on-Sea	SH8480
SPF	53°14'N	04°05'W	GBGD	Ogwen Estuary field	SH6172
TYC	53°15'N	03°49'W	GBGD	Tal-y-Cafn	SH7873

Appendix 2 The proportion of juveniles (95% CIs; number of catches) in the flocks based on the individuals-based index developed by Clark *et al.* 2004 for three different time periods. Data presented in Figure 4 are the August to March figures.

Winter	August to March	October to March	April to July
1980/1981	0.1 (0.08 - 0.12; 4)	0.1 (0.08 - 0.13; 4)	0.72 (0.64 - 0.78; 1)
1981/1982	0.3 (0.25 - 0.36; 6)	0.14 (0.1 - 0.19; 5)	0.52 (0.39 - 0.64; 1)
1982/1983	0.2 (0.16 - 0.25; 9)	0.17 (0.13 - 0.22; 7)	0.42 (0.35 - 0.5; 4)
1983/1984	0.16 (0.12 - 0.2; 3)	0.62 (0.44 - 0.78; 1)	0.43 (0.3 - 0.56; 2)
1984/1985	0.15 (0.12 - 0.19; 1)	0.15 (0.12 - 0.19; 1)	0.17 (0.15 - 0.2; 2)
1985/1986		0.19 (0.15 - 0.23; 2)	
1986/1987	0.16 (0.13 - 0.2; 4)		0.62 (0.53 - 0.7; 1)
1987/1988	0.39 (0.3 - 0.48; 1)	0.39 (0.3 - 0.48; 1)	
1988/1989	0.08 (0.05 - 0.12; 1)	0.08 (0.05 - 0.12; 1)	
1989/1990	0.00 (0-1; 1)		0.57 (0.48 - 0.64; 1)
1990/1991	0.11 (0.09 - 0.15; 2)	0.11 (0.09 - 0.15; 2)	
1991/1992	0.25 (0.18 - 0.33; 2)		
1992/1993	0.11 (0.09 - 0.14; 2)	0.11 (0.09 - 0.14; 2)	
1993/1994	0.2 (0.16 - 0.25; 2)	0.24 (0.18 - 0.3; 2)	
1994/1995	0.43 (0.36 - 0.51; 3)	0.4 (0.32 - 0.5; 2)	
1995/1996	0.32 (0.28 - 0.37; 3)	0.32 (0.27 - 0.38; 2)	0.14 (0.11 - 0.18; 2)
1996/1997	0.23 (0.19 - 0.28; 4)	0.09 (0.05 - 0.15; 2)	
1997/1998	0.3 (0.26 - 0.34; 3)	0.29 (0.25 - 0.34; 3)	
1998/1999	0.3 (0.25 - 0.35; 6)	0.16 (0.11 - 0.24; 5)	0.33 (0.24 - 0.44; 1)
1999/2000	0.21 (0.16 - 0.28; 4)	0.25 (0.19 - 0.33; 4)	0.44 (0.39 - 0.48; 1)
2000/2001	0.34 (0.29 - 0.4; 4)	0.18 (0.14 - 0.24; 3)	
2001/2002	0.37 (0.32 - 0.43; 5)	0.34 (0.29 - 0.41; 4)	
2002/2003	0.3 (0.25 - 0.35; 4)	0.28 (0.17 - 0.42; 3)	
2003/2004	0.06 (0.04 - 0.09; 1)	0.06 (0.04 - 0.09; 1)	