Predicting oystercatcher food requirements on the Dee Estuary.

A report to Natural Resources Wales.

Richard A. Stillman & Kevin A. Wood

School of Applied Sciences,

Bournemouth University,

Christchurch House,

Talbot Campus,

Poole,

BH12 5BB

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1. Summary

In UK estuaries conflicts have routinely occurred between economic and conservation interests regarding shellfish such as cockles *Cerastoderma edule* and mussels *Mytilus edulis*. The harvest of these species is economically important, but shellfish also constitute the main overwinter food supply of the oystercatcher *Haematopus ostralegus*. In this report we use a simplified spreadsheet model to predict the overwinter food requirements of oystercatchers in the Dee Estuary and compare the predictions of this model with those of an individual-based model which has been used to advise the setting of Total Allowable Catch in the Dee Estuary over recent years.

The models are based on the energy requirements of the birds and the energy value of their shellfish food. The spreadsheet model predicts the amount of shellfish required to maintain high survival rates within the oystercatcher population. The individual-based model predicts how the survival rate within the oystercatcher population is related to the amount of shellfish food and the amount removed by shellfishing. Although more complicated, the individual-based model represents the system in a more realistic way and can simulate specific shellfishing scenarios.

The models produced relatively similar predictions, especially when it was assumed that birds fed on upshore and terrestrial food in addition to cockles. As the biomass of cockles has declined since 2008, the models predicted that the amount required by the birds became close to the total available in 2012. The cockle biomass during 2013 was lower than that during 2012 and the spreadsheet model predicted that the birds required virtually all of the cockle stocks available.

2. Introduction

Welsh estuaries are important sites for shellfish, such as cockles (*Cerastoderma edule* L.) and mussels (*Mytilus edulis* L.), which support commercial shellfisheries. These shellfish are also the principal overwintering food resource for migratory wading birds, including the Eurasian oystercatcher (*Haematopus ostralegus* L.). These shared shellfish resources have led to conflicts between economic and conservation interests across estuaries in northwest Europe (Tinker, 1974; Ens, 2006; Laursen *et al*., 2010). Enough shellfish must be left unharvested to allow the birds to meet their food requirements. The responses of oystercatchers and other wading bird species to insufficient food supplies during the overwinter period, which include reduced individual body condition, increased mortality and reduced population sizes, have been well-documented in the scientific literature (Camphuysen *et al*., 1996; Verhulst *et al*., 2004; Atkinson *et al*., 2003; Atkinson *et al*., 2005; Atkinson *et al*., 2010). Therefore, a central question facing statutory authorities of estuaries is: how much food should be left unharvested for the bird population?

Over recent years a detailed individual-based model has been used to predict the cockle food required by oystercatchers in the Dee Estuary (West 2009, 2010, 2011, 2012). Similar models have predicted the amount of food required by populations of shellfish-feeding birds (usually oystercatchers) to survive through winter in other sites (e.g. Goss-Custard *et al*. 2004; Stillman 2008; Stillman & Goss-Custard 2010; Stillman *et al*. 2010; West *et al*., 2011). By predicting the amount of food required by the birds, these models can be used in the process of setting shellfishing Total Allowable Catch. However, specialist knowledge is required to run the models. It would be preferable if a more simple approach could be used. An ideal would be a piece of software into which data on the number of birds and amount and type of shellfish are entered, which then predicts the amount of food required by the birds. The predictions should be accompanied by appropriate caveats, the assumptions used to calculated them, and confidence limits. The overall aim would be to allow non-modelling specialists to calculate bird food requirements.

A recent contract between Bournemouth University and the Welsh Government has started to develop such a model (Stillman & Wood, 2013). The purpose of the model is to calculate the food requirements of an oystercatcher population consuming mussels and/or cockles within a site. Data on the number of oystercatchers feeding on mussels and cockles, the time for which the population must be supported and the initial stocks of mussels and cockles are entered into the model. The model then calculates the amount of food required in the environment to maintain high survival within the bird population. This is calculated using the results of empirical and individual-based modelling studies of oystercatchers in shellfisheries throughout the UK. The amount of mussel and shellfish stocks remaining after the bird requirements have been removed can then be used to set the Total Allowable Catch for shellfishing.

The purpose of the current project is to use this simplified model to predict the amount of cockle food required by oystercatchers in the Dee Estuary, an internationally important overwintering site (Figure 1; Holt *et al*., 2012). Data on the abundance of cockles and birds at the start of winter are used to calculate the amount of cockles that needs to be reserved for the birds to ensure that they can survive through the winter. The maximum shellfishing quota can then be calculated from the total amount of cockles minus the amount required by the birds. Predictions are made for 2008 to 2013 and compared to the predictions of the individual-based model run in previous years.

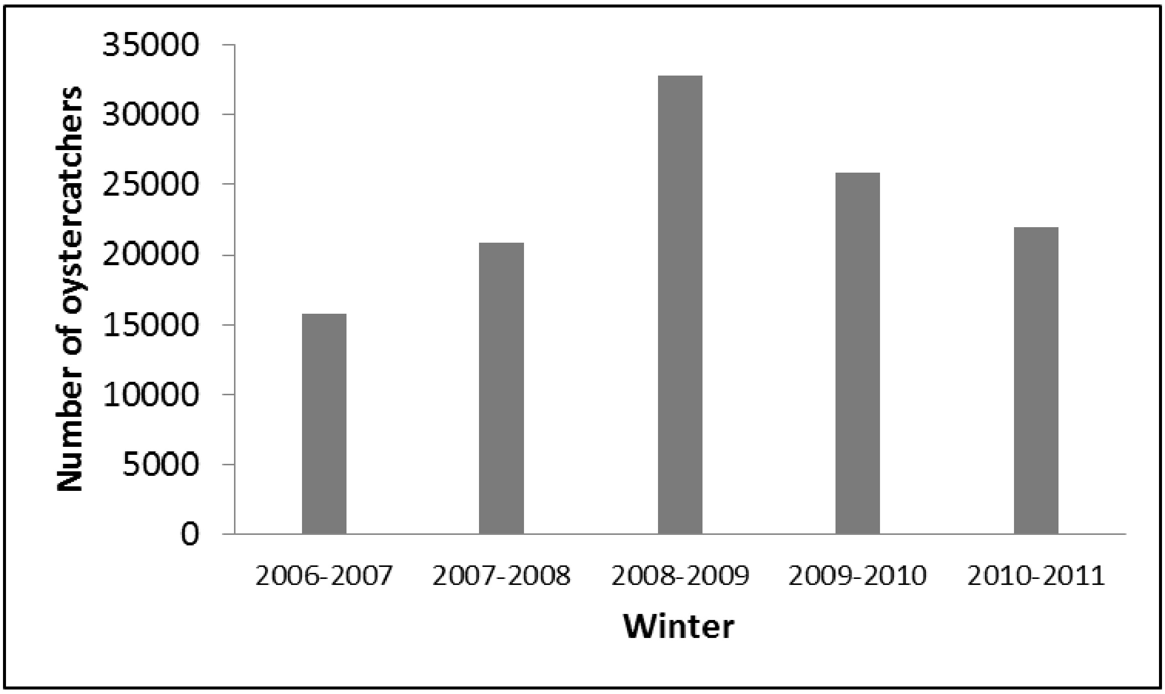

Figure 1: The peak overwinter oystercatcher counts for the Dee Estuary, recorded during the Wetland Bird Survey (WeBS) counts (Holt et al., 2012).

3. A spreadsheet model for estimating oystercatcher food requirements

In order to estimate the oystercatcher food requirements for the Dee Estuary, we used the spreadsheet model developed by Stillman & Wood (2013). The purpose of the spreadsheet model is to calculate the ecological requirement of an oystercatcher population consuming mussels and cockles within a site. Data on the number of oystercatchers feeding on mussels and cockles, the time for which the population must be supported and the initial stocks of mussels and cockles are entered into the model. The ecological food requirements of the birds (the amount of food required in the environment to maintain high survival) is calculated from the physiological requirements of the oystercatcher population (the amount actually eaten) and an ecological multiplier (measuring how much greater the ecological requirements are than the physiological requirements). More food needs to be reserved in the environment than the amount actually eaten because birds cannot find all of the food, some birds can be excluded from the food through competition and food is lost due to factors other than the birds. The amount of mussel and shellfish stocks remaining after the bird requirements have been removed can then be used to set the Total Allowable Catch for shellfishing. The spreadsheet model is intended to test whether this approach to calculating oystercatcher requirements can be applied quickly and reliably to a range of sites. If successful, the next step would be to create a piece of software that automated data entry and the generation of predictions.

3.1. Site-specific data

The model requires data on the number of oystercatchers supported by mussels and cockles in the site (N_{Oyc}) and the time period over which oystercatchers are supported (T). The number of oystercatchers supported by cockles and mussels can either be assumed to be the entire population, as these shellfish form the main prey of oystercatchers, or can be estimated from counts of the number of oystercatchers feeding on these prey. For example, birds feeding on other prey within the site, or feeding on prey outside of the site could potentially be excluded from calculations. The number of birds used in the model should either by the mean number counted within the site or the mean number counted feeding on mussels and cockles. The time for which the oystercatcher population needs to be supported should be the time for which the majority of the oystercatcher population occupies the site – for example, a typical wintering period would be from 1st September until 31st March. The proportion of the oystercatcher population feeding on mussels (p_{Mussel}), as opposed to cockles should also be estimated. This is used to calculate the amount of cockle and mussel biomass that needs to be reserved for the birds, and also to calculate the size of the ecological multiplier.

The model accounts for uncertainty in the minimum size of cockles and mussels consumed by oystercatchers. Calculations are either based on the typical minimum size of cockles and mussels consumed, 15mm and 30mm respectively, or lower minimum sizes that may be consumed when larger prey are absent, 10mm and 20mm respectively. It is assumed that there is no maximum size of cockle that can be consumed by oystercatcher but that mussels greater than 60mm in length cannot be consumed (Stillman & Wood, 2013). The model requires the fresh mass of cockles and mussels within the following size ranges to be calculated: cockles – 10mm to maximum ($B_{C10\text{-}max}$) and 15mm to maximum ($B_{C15\text{-}max}$); mussels – 20mm to 60mm ($B_{M20\text{-}60}$) and 30mm to 60mm ($B_{M30\text{-}60}$).

3.2. Default parameters

A number of default parameters are used in calculations which are assumed to be the same in all sites. The average body mass (g) of oystercatcher (B_{Oyc}) is set to 540g based on a review of body masses (Stillman & Wood, 2013). The energy content of mussels and cockles (E_{CM}) is set to 22 KJg^{-1}, the average value for bivalves (Zwarts *et al*. 1996). The efficiency with which mussels and cockles are assimilated (p_{assim}) is set to 0.85 (Kersten & Visser 1996). The ratio of AFDM to fresh mass ($p_{DryFresh}$) is set to 0.041, the average for mussels and cockles (Ricciardi & Bourget 1998). The ecological multiplier is set to 3.3 for oystercatcher populations consuming cockles or a mixture of cockles and mussels (M_{CM}), and to 7.1 for oystercatcher populations just consuming mussels (M_M) (Stillman & Wood, 2013).

3.3. The model

The model has two alternative ways of calculating the daily energy requirements of each oystercatcher in the population. If no data are available on overwinter temperature the model calculates daily energy requirements from body mass using the all bird equation of Nagy (1987).

$$E_{Oyc} = 10.5\left(B_{Oyc}\right)^{0.681} \qquad \text{Equation 1}$$

where E_{Oyc} = daily energy requirements of each oystercatcher (KJ) and B_{Oyc} = body mass (g). If suitable overwinter temperature data are available the model calculates daily energy requirements from energy expenditure in the absence of thermoregulation and the additional costs due to thermoregulation following Stillman *et al*. (2000) and Zwarts *et al* (1996c).

$$E_{Oyc} = \left(1 - p_{therm}\right)673.2 + p_{therm}\left(673.2 + 31.8\left(10 - t_{therm}\right)\right) \qquad \text{Equation 2}$$

where p_{therm} = proportion of time for which temperature is below that at which oystercatchers need to thermoregulate (i.e. 10 ^{o}c) and t_{therm} = mean temperature during this time. In this equation the daily energy demands of each oystercatcher is 673.2 KJ in the absence of thermoregulation. For every degree below 10^{o}c (Zwarts *et al*. 1996c) the daily energy requirements of each bird are increased by 31.8 KJ (Zwarts *et al*. 1996c).

The total ash-free dry mass (AFDM) (g) consumed by each oystercatcher is then calculated from the duration of the time period for which the birds need to be supported, the daily energy requirements of the bird, the energy content of cockles and mussels and the efficiency with which cockles and mussels are assimilated.

$$C_{Oyc} = \frac{T \cdot E_{Oyc}}{p_{Assim} \cdot E_{CM}} \qquad \text{Equation 3}$$

Where C_{Oyc} = total AFDM consumed by each bird (g AFDM), T = time period for which birds need to be supported (days), p_{Assim} = efficiency of assimilating energy from cockles and mussels and E_{CM} = energy content of cockles and mussels (KJ g^{-1}). The total AFDM (g) consumed by the oystercatcher population is calculated from the mean number of birds present.

$$C_{OycPop} = N_{Oyc}C_{Oyc} \qquad \text{Equation 4}$$

where C_{OycPop} = total AFDM consumed by oystercatcher population (g AFDM) and N_{Oyc} = mean number of birds present. The physiological food requirement of the population is found by converting AFDM to fresh mass and converting g to tonnes.

$$R_{Phys} = \frac{C_{OycPop}}{1000000 \cdot p_{DryFresh}} \qquad \text{Equation 5}$$

where R_{Phys} = Physiological food requirement of oystercatcher population (tonnes fresh mass including shell) and $P_{DryFresh}$ = ratio of AFDM to fresh mass including shell in cockles and mussels. The combined ecological multiplier (M), which accounts for the proportion of cockles-and mussel-feeding oystercatchers, is calculated from the proportion of birds feeding on mussels and cockles.

$$M = \begin{cases} M_{CM} & \text{if } p_{Mussel} < 1 \\ M_M & \text{if } p_{Mussel} = 1 \end{cases} \qquad \text{Equation 6}$$

where M_{CM} = ecological multiplier for oystercatchers feeding on cockles alone or a mixture of cockles and mussels, M_M = ecological multiplier for oystercatchers feeding on mussels alone and p_{Mussel} = proportion of birds feeding on mussels. Stillman & Wood (2013), based on a review of modelling and empirical studies, estimated M_{CM} as 3.3 and M_M as 7.1. The ecological requirement is then found by multiplying the physiological requirement by the combined ecological multiplier.

$$R_{Ecol} = M \cdot R_{Phys} \qquad \text{Equation 7}$$

where R_{Ecol} = ecological requirement (tonnes fresh mass including shell). The ecological requirement obtained from cockles (R_{EcolC}) and mussels (R_{EcolM}) is then calculated from the proportion of birds feeding on mussels.

$$R_{EcolC} = (1 - p_{Mussel}) \cdot R_{Ecol} \qquad \text{Equation 8}$$

$$R_{EcolM} = p_{Mussel} \cdot R_{Ecol} \qquad \text{Equation 9}$$

The final step is to calculate the biomass of cockles and mussels that are not required by the oystercatcher population. Calculations are either based on the typical minimum size of cockles and mussels consumed, 15mm ($X_{C10\text{-}max}$) and 30mm ($X_{C15\text{-}max}$) respectively, or lower minimum sizes that may be consumed when larger prey are absent, 10mm (X_{M20-60}) and 20mm (X_{M30-60}) respectively. The biomass not required by the birds is found by subtracting their requirements from the initial biomass of cockles and mussels.

$$X_{C10-max} = B_{C10-max} - R_{EcolC} \quad \text{Equation 10}$$

$$X_{C15-max} = B_{C15-max} - R_{EcolC} \quad \text{Equation 11}$$

$$X_{M20-60} = B_{M20-60} - R_{EcolM} \quad \text{Equation 12}$$

$$X_{M30-60} = B_{M30-60} - R_{EcolM} \quad \text{Equation 13}$$

Stillman & Wood (2013) explains the graphical output of the spreadsheet model and describes some example results.

4. Parameterising the spreadsheet model for the Dee Estuary

The main site-specific parameters required by the model are the time over which the oystercatcher population needs to be supported (i.e. duration of overwintering period), the size of the overwintering oystercatcher population feeding on shellfish, the start of winter biomass of shellfish within the size range consumed by oystercatchers and the proportion of energy obtained from shellfish. The following sections describe how these parameters were derived.

4.1. Duration of overwintering period

Following West (2009, 2010, 2011 & 2012) the time for which the of oystercatcher population needs to be supported was set to 196 days from 1 September until 15 March.

4.2. Size of overwintering oystercatcher population

The model only considers the shellfish food of the birds and does not consider changes in oystercatcher population size through the winter. The number of birds in the model is therefore the mean number consuming shellfish between September and March. Estimates of shellfish biomass were only available for cockles and so only the number of birds consuming this food resource were included in the model. Wetland Bird Survey (WeBS) high tide counts were used to estimate the total number of oystercatchers in the site during each winter month of each year from 2008 to 2013 (**Table 1**). The mean number of birds presented was calculated as the mean overwinter (September to March) high tide WeBS count. The number of birds feeding on cockles was assumed to be 80% of the total number of birds (B. Jones pers. obs.)

Table 1: Steps through which the numbers of oystercatchers included in the spreadsheet model each year were derived from monthly WeBS overwinter high tide counts. Peak and mean counts are from monthly counts between September and March each winter. Data were not available for 2012 onwards and so bird numbers were assumed to be the same in 2012 and 2013 as 2011. The number of birds feeding on cockles has been estimated as 80% of the total population (B. Jones pers. obs).

Year	Overwinter peak number of oystercatcher	Overwinter mean number of oystercatcher	Overwinter mean number of oystercatcher feeding on cockles
2008	18860	14078	11262
2009	25886	17117	13694
2010	21993	17417	13934
2011	26849	17108	13686

4.3. Biomass of shellfish at start of winter

Cockle biomass data were provided by Rhian Thomas (Natural Resources Wales) for surveys undertaken in April 2008, 2009, 2010, 2011, 2012 and 2013 (**Table 2**). The spreadsheet model requires as input the biomass of shellfish in September. The following approach was taken to account for growth in cockle biomass between April and September based on a survey of growth in the 2009 cockle year class between April and September 2010 (data provided by Bryan Jones). Between 10 May 2010 and 3 September 2010 the mean weight of the 2009 year class increased from 2.23 to 5.44 g and length increased from 18.6 mm to 24.6 mm. The mean density of the year class was 2129 m^{-2} in 10 May and 2608 m^{-2} on 3 September. Ten samples were taken in each month around a fixed point. The survey was conducted on a bed with a very high cockle density. Although the sample size was relatively small, there was no evidence of mortality, even on a very dense bed, while the biomass increased by 2.4 times. Growth in the 15-20mm size class was therefore assumed to be 2.4 times. No data were available for growth in the biomass of <15mm and >20mm cockles. Some growth of both size classes would be expected, and the 2009 year class grew through the 20mm size class between May and September 2010. Predictions were therefore made on two assumptions. First, that growth only occurred within <15mm and 15-20mm cockles (i.e. <20mm) and second, that growth occurred in all cockle size classes. Growth was assumed to occur at the same rate as measured in the 2009 year classes (i.e. 2.4 times between April and September). These assumptions can be consider lower and upper estimates of the amount of biomass available, with the actual value being somewhere between. Additionally it was assumed that cockles <15mm in April were >15mm in September.

Table 2: Steps through which the biomass of cockles in April was converted to the biomass of cockles available to birds in September. April cockle data are from intertidal surveys conducted by the Environment Agency and Natural Resources Wales (provided by Rhian Thomas (Natural Resources Wales)). Growth rate data were provided by Bryan Jones (Natural Resources Wales).

Year	April biomass of <15mm cockles (tonnes)	April biomass of 15-20mm cockles (tonnes)	April biomass of >20mm cockles (tonnes)	September biomass of >15mm cockles assuming only <20mm cockles grow (tonnes)	September biomass of >15mm cockles assuming all cockles grow (tonnes)
2008	19	16499	7079	46722	56633
2009	129	3947	14452	24234	44467
2010	7605	6567	3496	37509	42403
2011	21	3778	4988	14106	21089
2012	73	765	3799	5810	11129
2013	466	951	2340	5741	9017

4.4 Proportion of shellfish within the size range harvested

Oystercatchers were assumed to consume cockles >15mm whereas shellfishing harvests cockles >20mm. Therefore, the proportion of cockles >20mm in September needed to be calculated in order to determine the biomass of cockles that could potentially be harvested (**Table 3**). This proportion ranged from approximately 0.5 in 2010 when a high biomass of cockles <15mm in size were present in April, to approximately 1 in 2008, 2009 and 2010 when relatively few cockles <15mm in size were present in April.

Table 3: Steps through which the proportion of biomass of cockles >20mm in September was calculated. April cockle data are from intertidal surveys conducted by the Environment Agency and Natural Resources Wales (provided by Rhian Thomas (Natural Resources Wales)). Growth rate data were provided by Bryan Jones (Natural Resources Wales).

Year	April biomass of <15mm cockles (tonnes)	April biomass of 15-20mm cockles (tonnes)	April biomass of >20mm cockles (tonnes)	Proportion of cockles >20mm in September assuming only <20mm cockles grow (tonnes)	Proportion of cockles >20mm in September assuming all cockles grow (tonnes)
2008	19	16499	7079	1.00	1.00
2009	129	3947	14452	0.99	0.99
2010	7605	6567	3496	0.51	0.57
2011	21	3778	4988	1.00	1.00
2012	73	765	3799	0.97	0.98
2013	466	951	2340	0.81	0.88

4.5. Proportion of energy obtained from shellfish

Some of the simulations run by West (2009, 2010, 2011 and 2012) incorporated terrestrial and upshore food resources that could be consumed by birds when the cockle beds were covered by the tide. The upshore resources were assumed to be available for two hours longer than the cockle beds, which themselves were assumed to be available for 6 hours. The terrestrial food resources were available while the upshore areas and cockle beds were covered by the tide for 6 hours, but were only exploited by the birds during daylight. Birds were assumed to consume food at 0.87 mg s^{-1} while feeding on the upshore areas and 0.34 mg s^{-1} while feeding terrestrial. Goss-Custard et al. (2006) showed that cockle-feeding oystercatchers consume approximately 2 mg s^{-1}. Two sets of predictions were produced from the spreadsheet model, the first assuming that the birds obtained all of their energy requirements from cockles, the second assuming that a proportion was obtained from upshore and terrestrial food. The proportion of energy obtained from shellfish (p_{Energy}) in the second set of predictions was calculated as

$$p_{Energy} = \frac{6\ \text{hr} \cdot 2\ \text{mg s}^{-1}}{\left(2.4\ \text{hr} \cdot 0.34\ \text{mg s}^{-1}\right) + \left(2\ \text{hr} \cdot 0.67\ \text{mg s}^{-1}\right) + \left(6\ \text{hr} \cdot 2\ \text{mg s}^{-1}\right)} = 0.85 \qquad 14$$

This assumed that birds fed on cockles for 6 hrs with an intake rate of 2 mg s^{-1}, on the upshore areas for 2 hrs with in intake rate of 0.67 mg s^{-1} and on the fields for 3 hrs (assuming that 40% of the 6 hrs of high tide was in daylight) with an intake rate of 0.34 mg s^{-1}. To account for the energy obtained from upshore and terrestrial food the daily energy requirements of the birds in the spreadsheet model was multiplied by 0.85.

5. Predicted oystercatcher food requirements

5.1. Spreadsheet model

The spreadsheet model was used to predict how bird food requirements each year were influenced by different assumptions of the ecological multiplier and whether or not birds exploit upshore and terrestrial food supplies (**Table 4**). The ecological multiplier was varied due to the relatively large variation in the value estimated for different sites (Stillman & Wood 2013). The value of 3.3 was the average for all cockle dominated or mixed cockle and mussel sites reviewed, but included two values of over 5 predicted by early models. The value of 2.9 excluded these predictions. The value of 2.5 was the minimum observed on cockle dominated sites.

Table 4: The effect on predicted bird food requirements (tonnes fresh mass) of the size of the ecological multiplier and whether or not birds exploited upshore and terrestrial food supplies. Wetland Bird Survey (WeBS) data were not available for 2012 onwards and so bird numbers were assumed to be the same in 2012 and 2013 as 2011.

	Ecological multiplier = 2.5		Ecological multiplier = 2.9		Ecological multiplier = 3.3	
Year	Food = cockles, upshore, terrestrial	Food = cockles	Food = cockles, upshore, terrestrial	Food = cockles	Food = cockles, upshore, terrestrial	Food = cockles
2008	4640	5458	5382	6331	6125	7204
2009	5643	6638	6545	7700	7448	8762
2010	5740	6753	6658	7833	7577	8913
2011	5640	6633	6542	7694	7445	8755
2012	5640	6633	6542	7694	7445	8755
2013	5640	6633	6542	7694	7445	8755

The amount of cockle food (i.e. cockles >15mm) available to the birds varied among years and was also influenced by the two alternative assumptions of the rate of cockle growth between April and September (**Table 2**). The amount of cockle biomass not required by the birds was calculated in the spreadsheet model as the difference between the total biomass of cockles and the amount required by the birds. **Table 5** shows these values based on different assumptions of the growth rate of cockles, the value of the ecological multiplier and whether or not birds feed on upshore and terrestrial food in addition to cockles. The model predicted that over 5000 tonnes of cockles >15mm was not required by the birds during 2008 to 2011. During 2012 and 2013 the model predicted that the total amount of cockle biomass available was close to that required by the birds if no growth of >20mm cockles was assumed. When all cockle size classes were assumed to grow during 2012 and 2013 between 262 and 5489 tonnes of >15mm cockles were predicted to not be required by the birds, with lower values in 2013 (262 to 3377 tonnes) than in 2012 (2374 to 5489 tonnes).

It is important to note that the biomass of cockles not required by the birds refers to the biomass of >15mm cockles whereas the cockles exploited by fishing are >20mm. The biomass of >15mm cockles not required by birds (**Table 5**) was multiplied by the proportion of cockles >20mm in September (**Table 3**) to predict the biomass of >20mm cockles potential available to shellfishing. **Table 6** shows these values based on different assumptions of the growth rate of cockles, the value of the ecological multiplier and whether or not birds feed on upshore and terrestrial food in addition to cockles. The model predicted that over 5000 tonnes of cockles >20mm was not required by the birds during 2008 to 2011. During 2012 and 2013 the model predicted that less than 5000 tonnes of >20mm cockles were not required by the birds in all but one case. When all cockle size classes were assumed to grow during 2012 and 2013 between 231 and 5379 tonnes of >20mm cockles were predicted to not be required by the birds, with lower values in 2013 (231 to 2098 tonnes) than in 2012 (2327 to 5379 tonnes).

Table 5: The predicted biomass of >15mm cockles (tonnes fresh mass) not required by oystercatchers based on different assumptions of the growth rate of cockles, the value of the ecological multiplier (= 25, 2.9 or 3.3) and whether or not birds feed on upshore and terrestrial food in addition to cockles. (a) Only <20mm cockles assumed to grow between April and September. (b) All cockles assumed to grow between April and September.

(a) Only <20mm cockles assumed to grow

	Ecological multiplier = 2.5		Ecological multiplier = 2.9		Ecological multiplier = 3.3	
Year	Food = cockles, upshore, terrestrial	Food = cockles	Food = cockles, upshore, terrestrial	Food = cockles	Food = cockles, upshore, terrestrial	Food = cockles
2008	42082	41264	41340	40391	40597	39518
2009	18591	17596	17689	16534	16786	15472
2010	31769	30756	30851	29676	29932	28596
2011	8466	7473	7564	6412	6661	5351
2012	170	0	0	0	0	0
2013	101	0	0	0	0	0

(b) All cockles assumed to grow

	Ecological multiplier = 2.5		Ecological multiplier = 2.9		Ecological multiplier = 3.3	
Year	Food = cockles, upshore, terrestrial	Food = cockles	Food = cockles, upshore, terrestrial	Food = cockles	Food = cockles, upshore, terrestrial	Food = cockles
2008	51993	51175	51251	50302	50508	49429
2009	38824	37829	37922	36767	37019	35705
2010	36663	35650	35745	34570	34826	33490
2011	15449	14456	14547	13395	13644	12334
2012	5489	4496	4587	3435	3684	2374
2013	3377	2384	2475	1323	1572	262

Table 6: The predicted biomass of >20mm cockles (tonnes fresh mass) not required by oystercatchers based on different assumptions of the growth rate of cockles, the value of the ecological multiplier (= 25, 2.9 or 3.3) and whether or not birds feed on upshore and terrestrial food in addition to cockles. (a) Only <20mm cockles assumed to grow between April and September. (b) All cockles assumed to grow between April and September.

(a) Only <20mm cockles assumed to grow

	Ecological multiplier = 2.5		Ecological multiplier = 2.9		Ecological multiplier = 3.3	
Year	Food = cockles, upshore, terrestrial	Food = cockles	Food = cockles, upshore, terrestrial	Food = cockles	Food = cockles, upshore, terrestrial	Food = cockles
2008	42082	41264	41340	40391	40597	39518
2009	18405	17420	17512	16369	16618	15317
2010	16202	15686	15734	15135	15265	14584
2011	8466	7473	7564	6412	6661	5351
2012	165	0	0	0	0	0
2013	82	0	0	0	0	0

(b) All cockles assumed to grow

	Ecological multiplier = 2.5		Ecological multiplier = 2.9		Ecological multiplier = 3.3	
Year	Food = cockles, upshore, terrestrial	Food = cockles	Food = cockles, upshore, terrestrial	Food = cockles	Food = cockles, upshore, terrestrial	Food = cockles
2008	51993	51175	51251	50302	50508	49429
2009	38436	37451	37543	36399	36649	35348
2010	20898	20321	20375	19705	19851	19089
2011	15449	14456	14547	13395	13644	12334
2012	5379	4406	4495	3366	3610	2327
2013	2972	2098	2178	1164	1383	231

5.2. Comparison with individual-based model

The predictions made by West (2009, 2010, 2011 and 2012) are summarised in **Table 7**. Up to 2011 both models make similar predictions in terms of the biomass of cockles that can be harvested without being predicted to increase oystercatcher mortality, at least when it is assumed that birds feeding on food supplies other than cockles. Both models also predict that the amount of cockle food approaches the amount required by oystercatchers around 2012. The individual-based model predicted that upshore and terrestrial feeding was required to maintain high oystercatcher survival in the absence of fishing, and the spreadsheet model predicted that the oystercatchers required virtually all of the available food. In 2012 the individual-based model predicted that a TAC of up to 1500 tonnes could be set without increasing oystercatcher mortality. In the absence of upshore feeding the individual-based model predicted 11% mortality of oystercatchers. The individual-based model was rerun using 2013 cockle data in the absence of upshore feeding and predicted 25% mortality of oystercatchers. It was not possible to rerun the TAC simulations of the individual-based model, but the predictions in the absence of upshore feeding show that the cockle biomass in 2013 was less able to support the oystercatcher than that in 2012, suggesting that any TAC in 2013 should be lower than that in 2012.

Table 7: Summary of the predictions by made West (2009, 2010, 2011 and 2012). Total Allowable Catch (TAC) was calculated by multiplying the number of fishing licences modelled by the annual quota for each licence (80 tonnes). The mortality figures are predicted overwinter values for oystercatchers.

Year	Simulations assuming birds only feed on shellfish	Simulations assuming that birds feed on upshore and terrestrial food as well as shellfish
2009	0% mortality in absence of fishing. TAC of up to 4800 tonnes did not increase mortality.	No simulations run.
2010	6% mortality in absence of fishing. TAC of up to 1200 tonnes increased mortality to 7%.	0% mortality in absence of fishing. TAC of up to 1200 tonnes did not increase mortality.
2011	4.3% mortality in absence of fishing. TAC of up to 4000 tonnes, with daily quota of 300 kg, did not increase mortality. TAC of 4000 tonnes, with daily quota of 400 kg, increased mortality to 5.2%.	0% mortality in absence of fishing. TAC of up to 4000 tonnes, with daily quota of either 300 or 400 kg, did not increase mortality.
2012	11% mortality in absence of fishing No simulations run to predict effect of TAC on mortality.	0% mortality in absence of fishing. TAC of up to 1500 tonnes did not increase mortality. Mortality increased with TACs of 2000 tonnes and above. 7% mortality with a TAC of 2000 tonnes. 18% mortality with a TAC of 2500 tonnes.

6. Conclusions

The purpose of this report was to use a recently developed spreadsheet model of Stillman & Wood (2013) to estimate the overwintering food requirements of the Dee Estuary oystercatcher population and to compare these predictions with those of a more detailed individual-based model (West 2009, 2010, 2011, 2012).

Both models have their advantages and disadvantages. The individual-based model can simulate the system in more detail, and predict, for example, how the daily quota or distribution of fishing between beds affects the birds. It also directly predicts how changes influence the survival rate of the birds. It is however relatively complicated which it more difficult to clearly explain how it works and the assumptions it makes. It must also be run by someone with modelling experience.

The spreadsheet model is more simple and so its assumptions can be more clearly explained. It is also relatively straightforward to run, meaning that a person using the model does not need to have previous experience of modelling. It cannot however directly predict the survival of the birds or simulate important details of the real system in the way the individual-based model can, for example, between-bed differences in shellfish biomass or fishing effort.

Both models represented the alternative food resources of oystercatchers in a relatively simple way as no data were available. If subsequent surveys showed that sufficient alternative food resources existed for the birds, more cockles could potentially be harvested without being predicted to adversely affect the birds. Detailed quantitative surveys of the Dee Estuary benthic invertebrate community would need to be undertaken. Therefore the availability of alternative prey has important implications for the setting of shellfishing quotas.

The spreadsheet model described in this report does not replace the need for individual-based models but do have the advantage that they can be used by people without specialist modelling experience and using the type of data typically available from shellfisheries. A potential strategy is to routinely use such models as a first step in assessing bird food requirements. Individual-based models and other approaches could then be used if there is some doubt as to the validity of predictions (e.g. in sites with a large amount of human disturbance) or if it is predicted that the bird food requirements are either not met or are only just met by the cockle and mussel stocks within the site.

Although differing in their complexity and some assumptions the models produced relatively similar predictions, especially when it was assumed that birds fed on upshore and terrestrial food in addition to cockles. As the biomass of cockles has declined since 2008, the models predicted that the amount required by the birds became close to the total available in 2012. The cockle biomass during 2013 was lower than that during 2012 and the spreadsheet model predicted that the birds required virtually all of the cockle stocks available.

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