British Trust for Ornithology

BTO Research Report No. 128

THE EFFECT OF COMMERCIAL COCKLING ON THE NUMBERS OF WINTERING WATERFOWL ON THE SOLWAY ESTUARY

Report to Scottish Natural Heritage
by the British Trust for Ornithology

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April 1994

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Registered Charity No. 216652

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1. INTRODUCTION

No significant commercial fishery of the cockle *Cerastoderma edule* existed on the Solway estuary until late in 1987 when tractor dredging began on Mersehead Sands in addition to 60 hand cocklers (Figure 1). In 1988, there were four pairs of tractors, 25 hand cocklers and at least one boat suction dredging. The situation remained the same in 1989 with the exception that there were no hand cocklers. By 1990, six or seven boats had begun operating more widely on Carse Bay, Blackshaw Bank and Priestside/Midbank. Four pairs of tractors continued dredging on Mersehead Sands. In 1992, boat dredging was banned in the Solway but tractor dredging was allowed to continue.

Initially tractors dredged along the shallow edge of the tide as it advanced and retreated. Some tractors were modified with the addition of suction equipment mounted on a trailer. More recently fishermen have invested heavily in specially designed rotating sieves based on onion harvesters. These work on exposed dry sand at low tide. Suction dredging involves the employment of a hydraulic pump drawn over the cockle beds when they are covered by a depth of water sufficient to support a boat. The sediment collected by the suction dredge passes through a screen on board the boat which retains the commercial sized cockles. There is some disagreement over the relative damage caused to the cockles themselves during the sorting process of either method. The efficiency of suction dredging is unclear, some research suggests that boat dredgers are relatively inefficient at extracting cockles while Pickett (1973) suggested that it was a more efficient harvesting method, especially on low density beds.

The recent increase in the scale of cockle fishing on the Solway is illustrated by the landing statistics for the Ayr sea fishing district between 1983 and 1991 which consist almost entirely of catches from the Solway (Figure 2). The statistics do, however, include landings from bays along the north shore of the Solway, such as Wigtown, Auchencairn and Rough Firth, which are outside the area considered in this report. The landings are for boat fishing only and so are an underestimate of the amount of cockling that has occurred as a substantial amount of cockling is from land based cockle fishermen. Nevertheless, they provide an indication of the relative amounts of cockling that have occurred in each year. Landings rose from none in 1986 to 4519 tonnes in 1991, resulting in growing concern over the impact the fisheries were having on the estuarine community. This led to a year-long ban on suction dredging on the Scottish side of the Solway in October 1992, though tractor dredging continued.

There has been a considerable amount of work investigating the effect of cockling on stocks of cockles and other benthic invertebrates (Franklin & Pickett 1978, Perkins 1988, Bailey *et al.* 1990, Moore 1991), however, there have been no studies of the indirect effect on the birds that depend on these animals as a food source. In this report we compare the numbers of wintering waterfowl on the Solway Firth before and after the onset of commercial cockle fishing.

2. METHODS

The data analysed in the present study are from counts carried out as part of the Birds of Estuaries Enquiry (BoEE) organised by the British Trust for Ornithology. BoEE counts of wintering wildfowl and waders have been carried out on the Solway estuary each year since 1969. A team of volunteers made simultaneous counts of birds in different sectors around the estuary, during two hours either side of highwater on selected dates in each month of the year (for details of BoEE count methodology see Prater 1979, Chapter 6). The BoEE counts considered in the present analysis are those for the winters (September to March) 1983/84 to 1991/92. The area of the Solway estuary considered is that east of a line across the estuary from the western edge of Mersehead Sands on the north shore to Workington on the south shore.

Figure 1 shows the count sectors used in the analysis. The current BoEE count sectors corresponding to the numbered sectors in Figure 1 are given in Appendix 1. Although BoEE count sectors covered most of the shore of the Solway, several had to be excluded from the analysis. For some sectors, the boundaries were inconsistent over the study period, while for others, there was an incomplete set of counts because either, counting only began on them part way through the study period or they were not counted in particular months due to a lack of manpower. The problem of missing counts was largely circumvented by imputing them using a method devised by Underhill (1989). However, the predictability of missing counts using this method declines dramatically when more than half the counts are missing and so those sectors with more than half of the counts missing were excluded from the analysis. In addition, some counts may have been underestimates of the numbers of birds present, due to poor visibility or disturbance. Such counts were treated as missing counts and imputed. However, the original count was only replaced by the imputed value if the imputed value was greater than original count, since the count represents the minimum number of birds that were present. As the sectors considered only cover part of the estuary, trends in the numbers of birds identified in this report are not necessarily representative of the estuary as a whole.

Sectors 1-6 were classed as cockled and sectors 7-18 were classed as non-cockled (Figure 1), since the intensive and sustained commercial cockling was confined to mudflats within or adjacent to sectors 1-6. Although BoEE counts are predominantly of roosting birds at high tide, the count sectors on the Solway are large enough that the counts also provide a good indication of the numbers of birds feeding on mudflats directly out from the roost sites during the previous low tide. Most feeding birds on the Solway are forced up the shore by the tide and roost near to where they fed (Moser 1984). There will have been some movement between neighbouring sectors. However, there will have been little movement between cockled and non-cockled sectors as the cockled sectors were grouped together in the outer north of the estuary (Figure 1). Sector 11 included fields inland of sectors 10-13. The majority of birds roosting on these fields having fed on the estuary will have come from non-cockled sectors 10-13.

Trends in mean winter counts for cockled and non-cockled sectors over the study period were compared graphically, together with changes in the National Indices for each species. National Indices are calculated each year from the January BoEE counts on a large number of estuaries and provide an indication of the year-to-year changes in numbers nationwide. The arbitrary standard for the index is based on the January counts for 1973 (1971 for

wildfowl) and is set at 100 (for full details of how the indices are calculated see Cranswick *et al.* 1992). National Indices are not calculated for golden plover because a large proportion of the British population occur away from estuaries.

In order to examine changes in distribution between cockled and non-cockled sectors before and after the start of commercial cockling, we compared the differences between the cockled and non-cockled mean winter counts for the winters prior to 1987/88 with those for the winters after 1987/88, using t tests. The 1987/88 mean winter counts were excluded from the analysis because commercial cockling began part way through this winter and so we viewed it as a transitional period.

To see whether or not sectors within the two groups (cockled and non-cockled) were showing similar changes in bird numbers we determined the proportional difference between the numbers of birds using each count sector, before and after the start of commercial cockling. The proportional difference was calculated by totalling all counts in a sector before the 1987/88 winter, subtracting this from the total of all counts in the sector after the 1987/88 winter and then dividing the difference by the total number of birds counted in the sector in the two periods. Converting the change in numbers within a sector to a proportion of the overall total number of birds counted in the sector allows changes in different sectors to be compared directly. Proportional differences for cockled sectors were compared with those for non-cockled sectors, using t tests.

Species were only included in the analysis if they were regularly present on the Solway in nationally important numbers over the years being studied i.e. the species that had an average yearly peak, over five consecutive years, greater than 1% of the estimated British population. Of the 16 nationally important species, five (pintail, scaup, oystercatcher, bar-tailed godwit and curlew) were also of international importance i.e. had an average yearly peak, over five consecutive years, greater than 1% of the European population.

3. RESULTS

Figure 3 shows the changes in mean winter counts over the study period for cockled and non-cockled sectors, compared with changes in the National Indices for each species. Table 1 compares the differences between the mean winter counts in cockled and non-cockled sectors before and after the start of commercial cockling.

Table 2 shows, for each sector, the proportional differences between the total number of each species before and after the start of commercial cockling, while Figure 4 compares the mean proportional differences for cockled sectors with those for non-cockled sectors.

The results for each species are considered first before examining the results for all species combined.

3.1 Shelduck

Numbers in cockled sectors increased steadily during the cockling period, following an initial decrease (Figure 3a). Numbers in non-cockled sectors showed wider fluctuations, rising sharply at the start of cockling but falling, equally dramatically, between 1988 and 1990, before undergoing an increase again in 1991. The National Index remained fairly constant over the study period, with only a slight increase.

Comparison of the differences between the mean winter counts for cockled and non-cockled sectors before and after the start of cockling indicated an increased preference for non-cockled sectors during the cockling period, though the change was not significant (Table 1).

Proportional differences in the total number of birds before and after the start of cockling showed an overall increase, during the cockling period, in five of the cockled sectors, and an overall decrease in only one of the cockled sectors (Table 2). There was an equal number of overall increases and decreases amongst the non-cockled sectors. The mean proportional differences for cockled and non cockled sectors were both positive and did not differ significantly (Figure 4a).

3.2 Wigeon

Following an initial increase, numbers in cockled sectors fell during the cockling period, while numbers in non-cockled sectors rose sharply (Figure 3a). Numbers in cockled sectors were already exhibiting a decline prior to the start of cockling, in line with a general decrease in the National Index. However, the National Index increased slightly part way through the cockling period.

Comparison of the differences between the mean winter counts for cockled and non-cockled sectors before and after the start of cockling indicated an increased preference for non-cockled sectors during the cockling period, though the change was not significant (Table 1).

Proportional differences in the total number of birds before and after the start of commercial cockling showed an overall increase, during the cockling period, in two of the cockled sectors, and an overall decrease in two of the cockled sectors (Table 2). Three of the non-cockled sectors showed overall increases while six showed overall decreases. The mean

proportional difference was positive for cockled sectors but negative for non-cockled sectors, though the means were not significantly different (Figure 4a).

3.3 Teal

With the start of cockling, numbers in cockled sectors fell sharply and remained low throughout the cockling period despite an increase in the National Index during the cockling period (Figure 3a). The decrease in cockled sectors was matched by an increase in non-cockled sectors at the start of cockling but numbers subsequently fell sharply in non-cockled sectors just after the start of cockling.

Comparison of the differences between the mean winter counts for cockled and non-cockled sectors before and after the start of cockling showed a significant switch in preference from cockled to non-cockled sectors (Table 1).

Proportional differences in the total number of birds before and after the start of commercial cockling showed an overall increase, during the cockling period, in two of the cockled sectors, and an overall decrease in three of the cockled sectors (Table 2). Six of the non-cockled sectors showed overall increases while two showed overall decreases. The mean proportional difference was negative for cockled sectors but positive for non-cockled sectors, though the means were not significantly different (Figure 4a).

3.4 Pintail

Numbers in cockled sectors increased dramatically from 1983 and continued to rise through the cockling period (Figure 3a) despite a decline in the National Index over the same period. There were very few pintail in non-cockled sectors, though numbers did increase in the cockling period.

Comparison of the differences between the mean winter counts for cockled and non-cockled sectors before and after the start of cockling showed a significant increase in the preference for cockled sectors, during the cockling period (Table 1).

Proportional differences in the total number of birds before and after the start of commercial cockling showed an overall increase, during the cockling period, in three of the cockled sectors, and an overall decrease in two of the cockled sectors (Table 2). Three of the non-cockled sectors showed overall increases while two showed overall decreases. The mean proportional difference was positive for both cockled and non-cockled sectors and the means were not significantly different (Figure 4a).

3.5 Scaup

There were large fluctuations in numbers in both cockled and non-cockled sectors (Figure 3b). Numbers in cockled sectors rose dramatically between 1983 and 1988 but fell sharply part way through the cockling period corresponding with an equally dramatic increase in non-cockled sectors. Numbers were low in both cockled and non-cockled sectors by the end of the cockling period. The National Index remained fairly constant throughout the study period.

Comparison of the differences between the mean winter counts for cockled and non-cockled sectors before and after the start of cockling indicated a switch in preference from non-cockled sectors to cockled sectors during the cockling period, though the change was not significant (Table 1).

Proportional differences in the total number of birds before and after the start of commercial cockling showed an overall increase, during the cockling period, in four of the cockled sectors, and an overall decrease in two of the cockled sectors (Table 2). Four of the non-cockled sectors showed overall increases while five showed overall decreases. The mean proportional difference was positive for cockled but negative for non-cockled sectors, though the means were not significantly different (Figure 4b).

3.6 Oystercatcher

In cockled sectors, numbers increased prior to the start of cockling and remained fairly constant before decreasing in 1991 (Figure 3b). Numbers in non-cockled sectors increased steadily during the cockling period, following a decrease prior to the start of cockling. The National Index generally increased over the study period, though levelled off during the cockling period.

Comparison of the differences between the mean winter counts for cockled and non-cockled sectors before and after the start of cockling indicated a slight, non-significant, increase in the preference for cockled sectors during the cockling period (Table 1).

Proportional differences in the total number of birds before and after the start of commercial cockling showed an overall increase, during the cockling period, in four of the cockled sectors, and an overall decrease in two of the cockled sectors (Table 2). Five of the non-cockled sectors showed overall increases while seven showed overall decreases. The mean proportional differences were positive but very small for both cockled and non-cockled sectors and not significantly different (Figure 4b).

3.7 Ringed plover

Fluctuations in numbers in both cockled and non-cockled sectors followed a very similar pattern (Figure 3b). A marked initial increase at the start of cockling was followed by a sharp decline in 1989 and then an increase again in 1991. The National Index showed little overall change during the study period.

Comparison of the differences between the mean winter counts for cockled and non-cockled sectors before and after the start of cockling indicated a slight, non-significant decrease in the preference for non-cockled sectors during the cockling period (Table 1).

Proportional differences in the total number of birds before and after the start of commercial cockling showed an overall increase in all the cockled sectors, during the cockling period (Table 2). Seven of the non-cockled sectors showed overall increases while five showed overall decreases. The mean proportional difference was positive for both cockled and non-cockled sectors, though the increase in cockled sectors was significantly greater than that in non-cockled sectors (Figure 4b).

3.8 Golden plover

There was little change in numbers in cockled sectors over the study period though numbers in non-cockled sectors showed a sharp increase with the start of cockling (Figure 3b). During the cockling period numbers in non-cockled sectors declined temporarily before increasing again.

Comparison of the differences between the mean winter counts for cockled and non-cockled sectors before and after the start of cockling showed a significant increase in the preference for non-cockled sectors during the cockling period (Table 1).

Proportional differences in the total number of birds before and after the start of commercial cockling showed an overall increase, during the cockling period, in four of the cockled sectors and an overall decrease in two of the cockled sectors (Table 2). Ten of the non-cockled sectors showed overall increases while only two showed overall decreases. The mean proportional difference was positive for both cockled and non-cockled sectors, with the greater increase in non-cockled sectors, though the means were not significantly different (Figure 4b).

3.9 Grey plover

Numbers declined up to the start of cockling in both cockled and non-cockled sectors. However, during the cockling period, numbers in cockled sectors fluctuated about the same point while numbers in non-cockled sectors increased dramatically, in line with the National Index (Figure 3c).

Comparison of the differences between the mean winter counts for cockled and non-cockled sectors before and after the start of cockling indicated a switch in preference for non-cockled sectors during the cockling period, though the change was not significant (Table 1).

Proportional differences in the total number of birds before and after the start of commercial cockling showed an overall increase, during the cockling period, in just one of the cockled sectors and an overall decrease in the remaining five cockled sectors (Table 2). Half of the non-cockled sectors showed overall increases while the other half showed overall decreases. The mean proportional difference was negative for both cockled and non-cockled sectors, with the greater decrease in cockled sectors, though the means were not significantly different (Figure 4c).

3.10 Knot

Numbers in cockled sectors declined prior to the start of cockling but increased dramatically during the cockling period (Figure 3c). However, numbers in non-cockled sectors also increased during the cockling period. The National Index showed only a slight increase over the study period.

Comparison of the differences between the mean winter counts for cockled and non-cockled sectors before and after the start of cockling indicated an increased preference for cockled sectors during the cockling period, though the change was not significant (Table 1).

Proportional differences in the total number of birds before and after the start of commercial cockling showed an overall increase, during the cockling period, in half of the cockled sectors and an overall decrease in the remaining half (Table 2). Six of the non-cockled sectors showed overall increases while five showed overall decreases. The mean proportional difference was negative for both cockled and non-cockled sectors, with the greater decrease in cockled sectors, though the means were not significantly different (Figure 4c).

3.11 Sanderling

Less than five sanderling occurred on cockled sectors in any year. Numbers in non-cockled sectors increased over the study period, following an initial decline (Figure 3c). There was little change in the National Index over the study period.

Comparison of the differences between the mean winter counts for cockled and non-cockled sectors before and after the start of cockling indicated an increase in the preference for non-cockled sectors during the cockling period, though the change was not significant (Table 1).

Proportional differences in the total number of birds before and after the start of commercial cockling showed an overall decrease, during the cockling period, in the two cockled sectors that held any sanderling (Table 2). Four of the non-cockled sectors showed overall increases while five showed overall decreases. The mean proportional difference was negative for both cockled and non-cockled sectors, with the greater decrease in cockled sectors, though the means were not significantly different (Figure 4c).

3.12 Dunlin

In cockled sectors, a decline prior to the start of cockling continued during the cockling period despite a slight increase in the national Index over the study period (Figure 3c). Numbers in non-cockled sectors also fell prior to the start of cockling but the trend was reversed during the cockling period.

Comparison of the differences between the mean winter counts for cockled and non-cockled sectors before and after the start of cockling indicated a switch in preference from cockled to non-cockled sectors during the cockling period, though the change was not significant (Table 1).

Proportional differences in the total number of birds before and after the start of commercial cockling showed an overall increase, during the cockling period, in half of the cockled sectors and an overall decrease in the other half (Table 2). Seven of the non-cockled sectors showed overall increases while five showed overall decreases. The mean proportional difference was negative for cockled sectors but positive for non-cockled sectors, though the means were not significantly different (Figure 4c).

3.13 Bar-tailed godwit

Following a decline prior to the start of cockling, numbers in cockled sectors initially increased during the cockling period but declined in the final two years (Figure 3d). The general decline in cockled sectors was more or less in line with the National Index. Numbers in non-cockled sectors rose and fell more erratically over the study period.

Comparison of the differences between the mean winter counts for cockled and non-cockled sectors before and after the start of cockling indicated an increase in the preference for non-cockled sectors during the cockling period, though the change was not significant (Table 1).

Proportional differences in the total number of birds before and after the start of commercial cockling showed an overall increase, during the cockling period, in two of the cockled sectors and an overall decrease in four cockled sectors (Table 2). Seven of the non-cockled sectors showed overall increases while five showed overall decreases. The mean proportional difference was negative for cockled sectors but positive for non-cockled sectors, though the means were not significantly different (Figure 4d).

3.14 Curlew

Numbers in cockled sectors recovered slightly during the cockling period, following a decline prior to the start of cockling (Figure 3d). Numbers in non-cockled sectors were more erratic first decreasing and then increasing during the cockling period. There was a slight increase in the National Index over the study period.

Comparison of the differences between the mean winter counts for cockled and non-cockled sectors before and after the start of cockling indicated a slight decrease in the preference for non-cockled sectors during the cockling period, though the change was not significant (Table 1).

Proportional differences in the total number of birds before and after the start of commercial cockling showed an overall increase, during the cockling period, in two of the cockled sectors and an overall decrease in four cockled sectors (Table 2). Just three of the non-cockled sectors showed overall increases while nine showed overall decreases. The mean proportional difference was very small and positive for cockled sectors and very small but negative for non-cockled sectors. The means were not significantly different (Figure 4d).

3.15 Redshank

Prior to the start of cockling, numbers in cockled sectors increased while numbers in non-cockled sectors decreased, however, both showed a similar pattern during the cockling period with an initial decrease followed by an increase (Figure 3d). There was a slight increase in the National Index over the study period.

Comparison of the differences between the mean winter counts for cockled and non-cockled sectors before and after the start of cockling indicated a slight decrease in the preference for non-cockled sectors during the cockling period, though the change was not significant (Table 1).

Proportional differences in the total number of birds before and after the start of commercial cockling showed an overall increase, during the cockling period, in half of the cockled sectors and an overall decrease in the other half (Table 2). Likewise, half of the non-cockled sectors showed overall increases and half showed overall decreases. The mean proportional difference was very small and negative for both cockled and non-cockled sectors, and not significantly different (Figure 4d).

3.16 Turnstone

Numbers in cockled sectors mirrored closely changes in the National Index increasing for most of the cockling period and then declining at the end (Figure 3d). There were wide fluctuations in the numbers on non-cockled sectors throughout the study period.

Comparison of the differences between the mean winter counts for cockled and non-cockled sectors before and after the start of cockling indicated a slight decrease in the preference for non-cockled sectors during the cockling period, though the change was not significant (Table 1).

Proportional differences in the total number of birds before and after the start of commercial cockling showed an overall increase, during the cockling period, in two of the cockled sectors and an overall decrease in four of the cockled sectors (Table 2). Four of the non-cockled sectors showed overall increases and five showed overall decreases. The mean proportional difference was very small and positive for both cockled and non-cockled sectors, and not significantly different (Figure 4d).

3.17 All species

Figure 5 shows the mean winter counts over the study period of all species combined for cockled and non-cockled sectors. The counts in the two groups of sectors show a very similar pattern of change up to the final year of the cockling period when they diverge dramatically. In the 1991/92 winter numbers of birds decreased considerably in cockled sectors and increased considerably in non-cockled sectors.

Comparison of the differences between the all species mean winter counts for cockled and non-cockled sectors before and after the start of cockling indicated a switch in preference from cockled to non-cockled sectors during the cockling period, though the change was not significant (Table 1).

Considering all species together, proportional differences in the total number of birds before and after the start of commercial cockling indicated an overall decline in numbers as result of cockling in two of the cockled sectors but an overall increase in four of the cockled sectors (Table 2). Eight of the non-cockled sectors showed overall increases while four showed overall decreases. The mean proportional difference, considering all species, was positive for both cockled and non cockled sectors (Figure 6). Although the mean was greater for non-cockled sectors the difference was not significant.

4. DISCUSSION

Most of the existing information on the effect of cockling on birds comes from casual observations on the Wadden Sea in Holland. Overfishing there is thought to have been the cause of a mass starvation of eider *Somateria mollissima* (Huggett 1992). Similarly, declines in the numbers of purple sandpiper *Calidris maritima* and turnstone are considered to be the result of the destruction of mussel *Mytilus edulis* beds by suction dredgers (Huggett 1992). More recently on the Wash, large-scale starvation of Oystercatchers in the 1992/93 winter was considered to be due to failure of spat fall over several years possibly as a result of a series of warm winters (Clark 1993).

Cockle dredging may not only effect stocks of cockles it can also have an effect on non-target species of invertebrates and plants. Therefore, the effect of cockle fisheries on birds may not be confined to those species that are competing directly with the fishermen for cockles. Moore (1991) found samples of sediment taken the day after suction dredging had fewer taxa and a reduction in the mean abundance of individual species. The polychaete *Pygospio elegans*, the bivalve *Macoma baltica* and the snail *Hydrobia ulvae* were all seriously affected. In Auchencairn Bay, *Zostera* beds were completely destroyed by suction dredging (Perkins 1988).

On the Solway, the species that appeared to suffer most as a result of commercial cockling were teal and golden plover. However, the decline in teal numbers in cockled sectors occurred in the first year of cockling, when it was least intense, suggesting there is an alternative reason for the decline. Numbers of teal in cockled sectors, in fact, showed a slight recovery over the cockling period. Golden plover feed primarily on inland fields and use estuaries mainly for roosting, so a reduction in food as a result of cockling is an unlikely explanation for their decline in cockled sectors. However, declines may be the result of increased disturbance of roosts by cockling operations.

Cockle fishing may also have a positive effect on the numbers of some species that could benefit from the scavenged remains of cockles and other invertebrates damaged or disturbed by dredging. Discarded cockles can suffer physical damage, and stress due to repeated exposure and burial (Perkins 1988). Suction dredging, in particular, results in a considerable amount of damage to undersized cockles. On Lavan Sands in Wales, up to 21% of cockles returned to the seabed were damaged (Cook 1991), while in Auchencairn Bay, a large number of under-sized cockles washed ashore were thought to be cockles discarded by dredgers. Tractor dredging has been said to cause less damage, though cockles are crushed or forced to the surface by the weight of the tractor wheels (Cook 1988). The relative physical damage to cockles by either tractor dredging or boat dredging is likely be have changed as modifications are made to equipment almost continuously.

Increases in the numbers of oystercatcher and gulls *Larus sp.* in the Wadden Sea are thought to be a result of food items being made more readily available by the cockle fishery (Huggett 1992). Gulls were not considered in the present analysis though oystercatchers showed little sign of increasing or decreasing in number as a result of commercial cockling. It has been suggested that scaup and dunlin numbers on the Solway estuary may have increased for the same reason (Huggett 1992). Although there is some evidence, from the present study, of a positive effect of cockling on scaup numbers there is, if anything, a negative effect on dunlin. The species that appeared to have benefitted most from cockling

on the Solway were pintail and ringed plover. Pintail do feed on bivalves such as cockles and *Macoma baltica* (Rehfisch *et al.* 1991), so it is likely they will benefit if these prey items are made more readily available. Ringed plover are short-billed surface feeders that may also benefit from discarded or disturbed invertebrates that would otherwise burrow too deep for them to reach.

Looking at all species together, there is a suggestion that commercial cockling on the Solway may have had a negative effect on the overall numbers of birds in cockled sectors, particularly towards the end of the cockling period. It may be that initial short-term gains from scavenging are eventually outweighed by the continued reduction in stocks of invertebrates. Data of overall cockle biomass from the years 1989 to 1991 show that there was an 80% decline in 1991 from the levels of the previous two years (Bailey *et al.* 1991, 1992). Around Carsethann it was even greater with cockle biomass declining from 2,100 to just two. This was attributed to substrate erosion through natural causes. Erosion events on another large estuary, the Severn, have been shown to have substantial effect on the distribution of waterfowl in winter (Clark and Pr_s-Jones 1994). Such changes may cause larger effects than those of commercial cockling if it is at a level where it does not affect spatfall. Studies on the Exe have shown that another bivalve, the mussel (*Mytilus edulis*), has shown high levels of density dependence in first year settlement and first year winter mortality (McGrorty *et al.* 1990). If similar mechanisms operate on the Solway for cockles and other invertebrates then commercial cockling may not have a significant effect unless a high proportion of Solway cockles are harvested.

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Acknowledgements

This study was funded by Scottish Natural Heritage and we thank, in particular, Roy Cameron and Vincent Fleming for their input to the project. We would also like to thank Chris Lumb from English Nature, David Harris from the Cumbria Sea Fisheries Committee and Norman Holton from the Royal Society for the Protection of Birds for cockling information. We are grateful to the count organisers and all the volunteer counters on the Solway for their tireless work in often difficult conditions, and to Ray Waters and Carol Powley of the BTO Estuaries Unit for collating and computerising the count data. We thank Sophie Foulger for helping with the data inputting and the final preparation of the report.

Appendix 1 BoEE subsites and count sectors on the Solway corresponding to the sector numbers used in the present report.

Sector No.	BoEE Subsite	BoEE Sector Name
1	Outer North Solway	Southerness
2	"	Gillfoot Bay
3	"	Borron Point
4	"	Carse Bay
5	Inner North Solway	Caerlaverock
6	"	Priestside
7	"	Powfoot
8	"	Annan Waterfoot
9	Inner South Solway	Rockcliffe
10	"	Sandsfield to Glasson
11	"	Inland Fields
12	"	Viaduct to Longdyke
13	"	Calvo to Grune
14	Outer South Solway	Heather Bank - Dick Trod Lane
15	"	Mealo - Mawbray
16	"	Maryport - Allonby
17	"	Flimby - Maryport
18	"	Workington - Flimby

Appendix 2Tables

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Species	Before start of cockling	After start of cockling	
Shelduck	-141±155	-242±164	
Wigeon	-83±140	-511±175	
Teal	270±24	-44±20	
Pintail	298±63	548±55	
Scaup	-130±212	24±418	
Oystercatcher	4068±1673	4316±2090	
Ringed plover	-154±17	-117±14	
Golden plover	-859±65	-2016±376	
Grey plover	34±66	-139±58	
Knot	1430±484	2091±389	
Sanderling	-143±25	-213±17	
Dunlin	1716±845	-282±574	
Bar-tailed godwit	-353±474	-581±144	
Curlew	-2411±269	-2145±303	
Redshank	-382±183	-153±100	
Turnstone	-305±54	-235±57	
All species	15±2487	-2661±3540	

Table 1. Mean differences between the mean winter counts in cockled and non-cockled sectors in the four years before and after the start of commercial cockling. * indicates $p<0.05$, ** indicates $P<0.001$.

Species	Sector										
	1	2	3	4	5	6	7	8	9	10	11
Shelduck	0.34	0.18	0.09	0.03	-0.32	0.34	-0.33	0.63	-0.03	0.17	0.27
Wigeon	-0.10	---	---	0.52	-0.29	0.51	-0.52	0.69	-0.13	0.34	-1.00
Teal	1.00	---	-0.87	0.36	-0.62	-0.57	0.54	0.95	0.38	0.25	---
Pintail	-0.68	1.00	---	0.36	0.41	-0.41	-1.00	---	0.72	0.58	---
Scaup	-0.08	0.90	0.20	0.28	-0.90	0.63	0.56	-0.40	0.26	-0.18	---
Oystercatcher	0.04	0.03	0.17	-0.15	-0.05	0.00	0.14	0.52	-0.27	-0.35	-0.50
Ringed plover	0.51	0.19	0.04	0.45	0.78	0.84	-0.35	-0.18	0.31	-0.18	0.06
Golden plover	0.26	0.22	-1.00	0.69	-0.05	0.34	-0.27	0.18	0.31	-0.05	0.34
Grey plover	-0.03	-0.12	-0.24	0.30	-0.90	-0.27	-0.74	-0.74	0.32	-0.36	0.77
Knot	0.32	0.61	0.37	-0.40	-0.91	-0.38	0.93	0.54	---	-0.60	-0.90
Sanderling	-0.21	-1.00	---	---	---	---	---	-1.00	---	-1.00	-0.72
Dunlin	0.27	-0.05	0.13	0.50	-0.88	-0.39	0.29	0.84	0.39	-0.11	0.01
Bar-tailed godwit	-0.39	-0.08	0.11	0.75	-0.97	-0.73	0.90	0.40	1.00	0.13	0.79
Curlew	-0.06	-0.08	-0.04	0.28	-0.20	0.11	-0.23	0.30	-0.05	-0.04	-0.12
Redshank	0.03	-0.03	-0.03	0.20	-0.45	0.16	0.35	0.09	-0.03	-0.21	0.18
Turnstone	0.19	-0.17	-0.38	-0.08	0.75	-0.20	-0.55	-0.15	---	---	---
All species	0.10	0.15	0.16	0.15	-0.17	-0.10	0.31	0.40	0.14	-0.01	-0.11

Table 2. Proportional differences between the total number of each species counted in the four years before and after the start of commercial cockling (total after-total before/total after+total before). The missing values are where a species was not recorded in the sector.

Appendix 3Figures

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