Chapter 4

Identification and size estimation of *Spisula subtruncata* and *Ensis americanus* from shell fragments in stomachs and faeces of Common Eiders *Somateria mollissima* and Common Scoters *Melanitta nigra*

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Submitted to *Atlantic Seabirds (2007)*

Abstract

This study describes methods to reconstruct the size of ingested *Spisula subtruncata* and *Ensis americanus* in stomachs, guts and faeces of seaduck. These two bivalve species constituted staple foods of Common Eiders *Somateria mollissima* and Common Scoters *Melanitta nigra* in the SE North Sea. The ducks crush these shellfish in their muscular gizzards, leaving only tiny fragments in most samples that may be obtained in the field. We show that prey sizes (shell lengths) can still be estimated from such samples, by taking specific measurements from the shells' hinges or from the thickness of shell fragments. Even though the hinges of both bivalve species are the thickest parts of the shell, few remain pass the stomach of a sea duck undamaged. However, even broken hinges can be used to estimate prey size by regression analysis, using specific measurements of certain parts. Shell thickness is also related to shell size so this parameter can also be used to reconstruct shell size. In *Spisula* specific, recognizable parts of the shell can often be recognised in samples of crushed shells. In *Ensis* samples, such specific parts are harder to find, but average thickness of several fragments within a sample, or the thickness of the thickest or thinnest parts present in the sample may be used. Suggested measurements correlated well with shell length in reference material. The applicability of these correlations was tested in experimental feeding trials with captive ducks that were fed with *Spisula* of known size. These tests showed that not all measurements taken from hinges or shell thickness of fresh shells could reliably be taken from fragments of the shells as present in the faeces. From the hinges, the so-called chondrophores were the most frequently recovered parts (some 11.5 % of those ingested), and these were also the most resilient to wear. Shell thickness could be measured from relatively many shell fragments, particularly from the ventral region of the shell. Precision from any individual shell fragment was rather low, but average sizes of *Spisula* fed to the ducks could be estimated rather well, using either hinge or shell thickness measurements. The methods were tested on shell fragments in field samples where the available prey spectrum was known from benthos sampling programs. Reconstructed sizes of both *Spisula* and *Ensis* from shell fragments found in stomachs of oiled scoters or in faeces from eiders roosting on an offshore sandbank compared well with sizes of these prey available in the vicinity. Both seaduck species showed size selection when eating these two shellfish prey species in the field.

Introduction

Common Scoters *Melanitta nigra* are common seaducks in The Netherlands, where they occur in flocks of up to >100,000 in nearshore waters (Leopold 1993, Leopold *et al.* 1995, Bijlsma *et al.* 2001, ICES 2005). In the 1990s, the scoters were joined by tens of thousands of Common Eiders *Somateria mollissima* that were driven out of the adjoining Wadden Sea by a shortage of their principal food, blue mussels *Mytilus edulis* and edible cockles *Cerastoderma edule* (Leopold 1993, Camphuysen *et al.* 2001, Ens & Kats 2004). Both species of seaduck were usually found over banks of trough shells *Spisula subtruncata* in Dutch coastal waters and it was generally assumed that these bivalves formed their staple diet (Leopold 1993, 1996, Leopold *et al.* 1995). However, *Spisula* stocks have been decreasing lately, while another bivalve, the American razor clam *Ensis americanus* has increased dramatically in abundance (Armonies 2001, Bult *et al.* 2004a, Craeymeersch & Perdon 2004). These long-bodied razor clams may be hard to swallow or crush in the gizzard, but if this species takes over as the dominant bivalve in Dutch coastal waters, the ducks may be forced to change their diet, or leave. Observations on ducks feeding close to land (Photo 4.1) have shown that scoters can eat this prey (Leopold & Wolf 2003, Wolf & Meininger 2004). Eiders too have been noted to take *Ensis*, through stomach analyses (Swennen & Duiven 1989, Thingstad *et al.* 2000, Ens *et al.* 2002, Laursen *et al.* in prep., ICES 2005) direct observations on feeding ducks (e.g. Leopold 2002a) and faeces analysis (Nehls & Ketzenberg 2002) but information for Dutch waters is still very scanty.

Diet studies on seaduck in the area have been hampered by lack of suitable material. Direct observations are hard to conduct in the North Sea, where scoters and eiders mostly feed outside telescope range. Such observations may also be biased towards large prey that need a lot of handling time, such as large *Ensis*. Indirect methods, such as stomach or faeces analysis thus have to be used. Seaduck are protected birds in Dutch waters, making shooting ducks for e.g. stomach analyses a hard option to follow (cf. Madsen 1954, Aulert & Sylvand 1997, Laursen *et al.* in prep.). Set-nets as used other parts of these birds' range from which large numbers of drowned ducks may be obtained (cf. Durinck *et al.* 1990, Meissner & Bräger 1990, Kallenborn *et al.* 1994, Rumohr 2002, Žydelis 2000, 2002) are not abundantly deployed in areas where the ducks concentrate in the Netherlands either. Major oil incidents have not recently killed large numbers of seaduck in Dutch waters that could be used for obtaining stomachs (cf Hughes *et al.* 1996, 1997). Only the recent die-off of Common Eiders (Camphuysen *et al.* 2001), has been seized to conduct stomach analyses (Ens & Kats 2004). Both Spisula and *Ensis* were found in the stomachs, but obviously, a study of starved birds may yield results that are hard to interpret.

Prey can also be studied if faeces of the ducks can be collected. Faeces contain the crushed shells of the prey eaten and these fragments may be used to study

Photo 4.1 Female Common Scoter *Melanitta nigra* handling *Ensis directus* off the Brouwersdam, SW Netherlands, 27 January 2004. Photo: Pim Wolf.

prey species taken and to reconstruct prey sizes. Such studies have been conducted on various species of shellfish eating birds in the Wadden Sea, where faeces can be collected with relative ease on tidal flats or on high tide roosts (e.g. Swennen 1976a, Nehls 1989, Dekinga & Piersma 1993, Hilgerloh 1999, 2000, Scheiffarth 2001, Nehls & Ketzenberg 2002). In these studies, prey size was assessed from the sizes of the hinges of ingested shells present in the faeces. The hinges are the thickest and hardest part of the shell and these sometimes remain intact even in badly fragmented shells. Empirical relationships between hinge size and shell size may than be used to back-calculate the original size of the ingested shells.

Faeces can only be collected where birds drop these on accessible places such as high tide roosts or mudflats used for feeding during low tide. Such studies have thus been limited to wildfowl, waders and gulls feeding in the intertidal. Seaduck, particularly scoters habitually rest at sea, and their faeces can not be collected here. Eiders however, often come ashore to rest, also when they feed in the North Sea. Exploratory observations on Eider droppings found along the Dutch mainland coast have indicated that *Spisula subtruncata* fragments were excreted in large quantities here (Leopold 1996).

Another problem for conducting diet studies on these birds is that information that relates hinge size to shell size for *Spisula* and *Ensis* is still lacking. Only Dekinga and Piersma (1993) used (small) *Spisula subtruncata* in feeding experiments with captive Red Knots *Calidris canutus*, but they found that the hinges of these shells usually got so damaged that shell size could not be estimated from faecal analysis. Likewise, the long and delicate *Ensis* hinges will probably mostly break up in a seaduck gizzard.

In this paper, we explore the possibilities to study the feeding habits of eiders and scoters, by analyzing shell fragments in faeces and stomachs. We focus on *Spisula subtruncata* and *Ensis americanus* as these are the most likely candidate staple foods in our study area. The feasibility to use hinges or shell thickness is explored in feeding experiments on captive Common Eiders and in field situations involving both species of seaduck and both species of prey. As hinges have used in many previous diet studies of molluscivores, we have first examined the possibility to use these in *Spisula* and *Ensis* as well. However, as the hinges of these shellfish may be very prone to breaking up in the muscular gizzard of a large seaduck (cf. Dekinga and Piersma 1993), we have also used shell thickness. Shell thickness is correlated to shell size (length), and therefore could, in theory, also be used to reconstruct original shell size. However, as opposed to the hinge which is a unique structure in a shell, shell thickness varies over the shell's length and width and unless clear reference points can be pinpointed that can still be identified in a sample of shell fragments, using this measure poses additional problems, which will be addressed.

Methods

Spisula subtruncata

Hinges

The first step in this study was to describe the hinges of *Spisula subtruncata* and *Ensis americanus*, to measure all parts that could conceivably be useful in faeces studies and relate these measurements, over a range of suitable prey sizes, to shell size. Hinges of *Spisula subtruncata* were examined under a stereo microscope fitted with an eye-piece micrometer. Nine measurements were taken: four from the right valve and five from the left valve. From the right valve we measured (Figure 4.1A): the maximum (diagonal) length (1) and maximal height of the chondrophore (2) and the lengths of the anterior and posterior lateral grooves (3 & 4). From the left valve we measured (Fig 4.1B and 1C): the maximum (diagonal) length (5) and maximal height (6) of the chondrophore, the distance between the two cardinal teeth (7) and the lengths of the anterior (8) and posterior (9) lateral teeth. Shell length (see Figure 4.2) was related to these measurements by linear regression (Table 4.1). Shell lengths (range: 15.24 to 32.31 mm) were distributed evenly over the total size range. Chondrophore and anterior lateral groove measurements resulted in the highest R^2- values.

Spisula shell thickness

Several reference points for measuring shell thickness were selected that would still be identifiable in samples of shell fragments. The first reference point is situated at the deepest point of the shell, near the top, directly under the hinge, along the

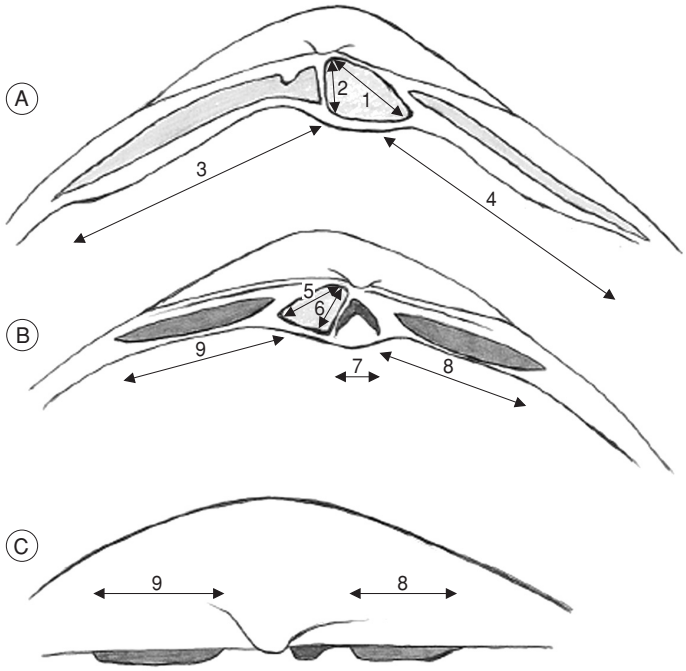

Figure 4.1 Right valve (A) and left valve (B & C) of *Spisula subtruncata*. Arrows and numbers indicate how measurements were taken of the different parts of the hinge. See text and Table 4.1 for the meaning of the numbers. Elevated teeth are depicted dark grey, depressions (grooves) light grey.

Table 4.1 Linear regression parameters used to estimate shell length (in mm) in Spisula subtruncata, from hinge measurements (numbers in left column refer to description given with Figure 1). All regressions for Spisula take the form: shell length = aX + b, with X = the specific measure in mm.

Spisula: Hinge measure	a	b	n	R^2
#1 chondrophore diagonal length right valve	7.36	8.26	41	0.94
#2 chondrophore maximal height right valve	9.41	7.93	41	0.93
#3 anterior lateral groove	3.45	0.54	41	0.95
#4 posterior lateral groove	3.32	2.51	41	0.87
#5 chondrophore diagonal length left valve	7.58	8.76	40	0.97
#6 chondrophore maximal height left valve	11.22	7.18	40	0.94
#7 distance between the cardinal teeth	21.51	2.06	40	0.57
#8 length of anterior lateral tooth	5.28	5.16	40	0.87
#9 length of posterior lateral tooth	5.30	4.73	40	0.80

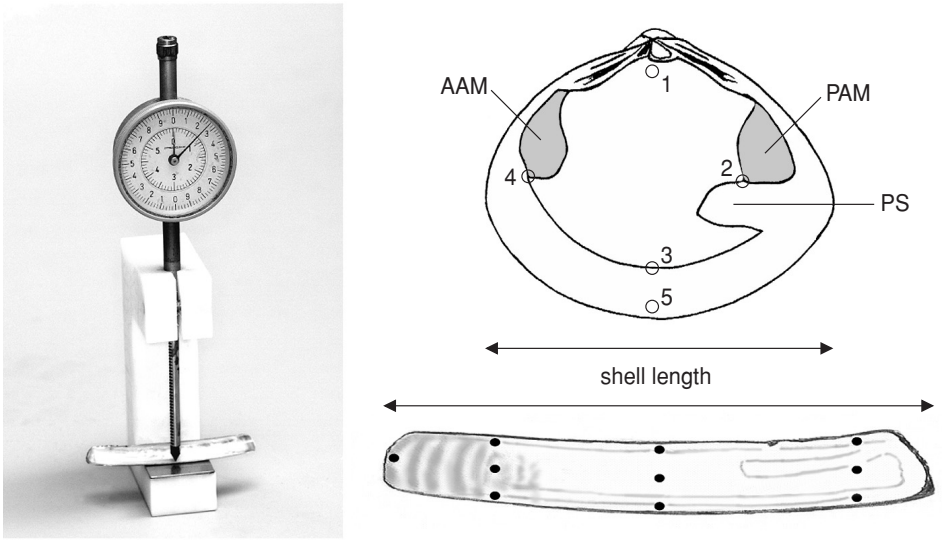

Figure 4.2 The micro thickness-meter that was used to measure shell thickness (photo left). Top-right: inside view of Spisula with reference points for measuring shell thickness (see Table 2). PL: pallial line with the pallial sinus (PS) and scars of anterior (AAM) and posterior (PAM) adductor muscles. Lower right: reference points in *Ensis*. Long horizontal arrows indicate how shell length was measured in either species.

dorsal-ventral median line (Figure 4.2). Points 2–4 lay along the dark 'pallial line' that runs along the outer margin of the shell and around the scars of the posterior and anterior adductor muscles. This pallial line (PL) marks the outer rim of the fleshy tissue of the living shellfish and is usually clearly visible in *Spisula*. It shows several characteristic bends that we could often pinpoint in samples of shell fragments. Point 2 sits at the ventral junction of the pallial line and posterior adductor muscle (PAM) imprint, point 3 sits at the ventral midpoint of the pallial line and point 4 at the ventral junction of the pallial line and anterior adductor muscle (AAM) imprint. Reference point 5 is between the ventral midpoint of the pallial line and the outer margin of the shell.

As fragments from left and right valves in stomach and faeces samples could not always be separated, we randomly selected left and right valves from our set of reference shells, thus keeping measurements within reference points independent. Again, shell length (range: 10.11 to 32.20 mm) was related to the different measurements (Table 4.2). All shell thickness measurements were taken with a micro thickness-meter from shells that were thoroughly air-dried, but still had the epidermis on (Figure 4.2).

Table 4.2 Linear regression parameters used to estimate shell length (in mm) in Ensis americanus, from measurements on shell thickness. All regressions for Ensis take the form: shell length = aX b, with X = shell thickness in mm.

Spisula shell thickness at:	a	b	n	R^2
Ref. point #1 (inner top):	26.10	0.210	63	0.51
Ref. point #2 (PAM):	21.39	0.428	63	0.67
Ref. point #3 (ventral PL):	21.58	0.410	63	0.71
Ref. point #4 (AAM):	23.75	0.399	63	0.60
Ref. point #5 (outer rim):	20.18	0.533	63	0.72

Ensis americanus

Hinges

Ensis americanus has a long and rather delicate hinge that is widest ventrally. The left side shows a prominent lateral gap here. From the left valve we measured: the maximum length (#1, A-D, Table 4.3 and Figure 4.3), the length from the anterior end to the gap (#2, A-B), the width of the gap (#3, B-C) and the length of the posterior 'island' (#4, C-D). Note that the length of (1) equals that of (2+3+4). From the right valve we measured: the maximum length (#5, I-F), the length without the posterior "head" (#6, I-H) and the width of the posterior head (#7, E-G). The precise manner in which these measurements were taken is depicted in Figure 4.3. Note that in measurement #5, the maximum length of the right valve was not measured to the ventral extreme (point F' in Figure 4.3), but to the midpoint of its ventral curve that was more often still intact in faecal samples (point F).

Ensis hinges were measured under a Zeiss Stereo Microscope SV6, fitted with a Zeiss AxioCam MRc digital camera, connected to a computer via integrated Axiovision4 software. This system became available for our research during our study and allowed for measurements to be taken from a computer screen using the appropriate magnification. 34 hinges were selected from shells distributed evenly over a range of shell lengths from 34.8 to 179.8 mm. Shell length was regressed against the different measurements. R_ values were generally high (Table 4.3). It was noted, however that measurement #7 was prone to error, if the hinge was not put flat under the microscope.

Ensis shell thickness

In *Ensis* shells the pallial line is less clear than in *Spisula*, particularly in faecal samples and clear reference points could not easily be found. Over the entire shell width, the valves proved to be thinnest at the anterior end and thickest near the hinge. Therefore, 10 different measurements of shell thickness were taken per valve (Figure 4.2). One reference point was taken near the (thin) anterior margin of the valve (along the median line, 3 mm from the top). Six reference points were

Table 4.3 Linear regression parameters used to estimate shell length (in mm) in *Ensis americanus*, from hinge measurements (numbers in left column refer to description given with Figure 4.3). All regressions for *Ensis* take the form: shell length = aX b, with X = the specific measure in mm.

Ensis: Hinge measure	a	b	n	R^2
#1 (A-D) maximum length in left valve	17.45	0.853	33	0.93
#2 (A-B) anterior end to the gap in left valve	22.87	0.790	30	0.91
#3 (B-C) gap width in left valve	378.61	1.040	29	0.75
#4 (C-D) posterior island length in left valve	111.61	0.700	31	0.86
#5 (I-F) maximum length in right valve	17.67	0.880	34	0.94
#6 (I-H) length to posterior "head" in right valve	25.95	0.717	33	0.84
#7 (E-G) width of posterior "head" in right valve	81. 70	0.959	30	0.92

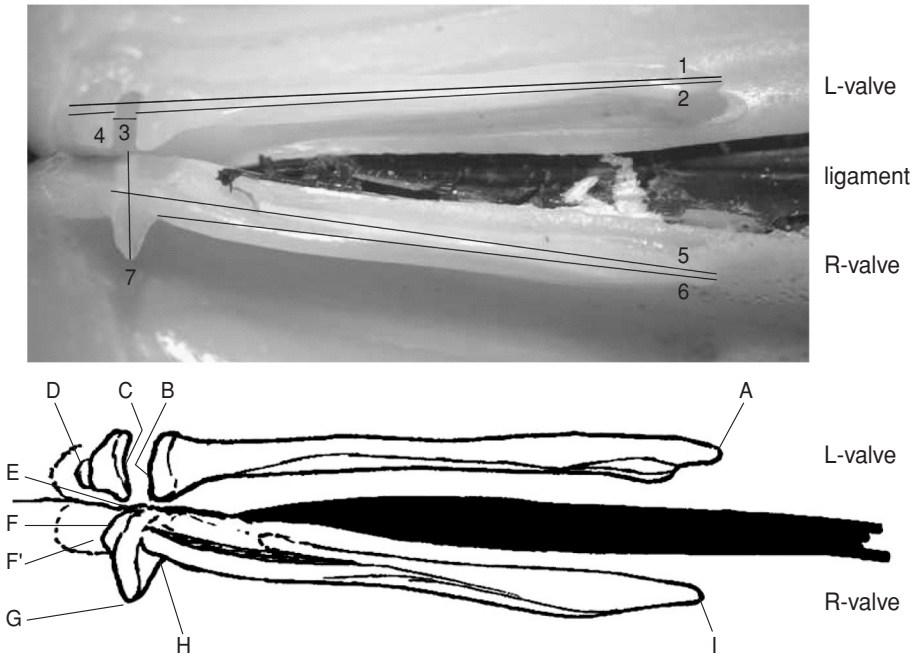

Figure 4.3 Pair of valves of *Ensis americanus*, joined by the outer ligament in between (black). In the photo (top) lines and numbers indicate how measurements were taken of the different parts of the hinge. See text and Table 4.3 for the meaning of the numbers. The lower panel shows a schematic drawing of an Ensis hinge, offering more contrast between the elevated (measured) ridges and the flat part of the valves below (inside view).

taken at 3 mm from the outer rim (evenly distributed over the length of the shell) and a final three along the median line of the shell. As reference material 19 *Ensis*-valves (ranging in length from 37.2 to 161.0 mm, left or right randomly selected) were used. Like in the reference *Spisula* shells, shell lengths were selected in such a way that this range of sizes was evenly covered. Shell length was regressed against shell thickness, using the largest values (the thickest part), the smallest values (the thinnest part), and the average thickness of all ten measurements (Table 4.4).

Table 4.4 Linear regression parameters used to estimate shell length (in mm) in *Ensis americanus*, from measurements on shell thickness. All regressions for *Ensis* take the form: shell length = aX + b, with X = shell thickness in mm.

Ensis shell thickness at:	a	b	n	R^2
thickest part	91.78	37.39	19	0.91
thinnest part	210.06	51.11	19	0.92
Average of all ten points	131.76	47.35	19	0.91

Feeding trials

Faeces of two captive Eiders were collected after these had been fed with live, intact *Spisula*. The Eiders were raised from the egg, and when they were full-grown, were kept on a diet of bivalves in outdoor cages with running seawater. The ducks were kept for experiments to determine the energetic costs of crushing and digesting bivalve prey. In each trial, one duck that had been kept without food for several hours was force-fed 8 to 15 live, intact *Spisula subtruncata* of the same size. The number of prey depended on prey size and *Spisula* used were: 24, 26, 28, 30, or 32 mm long. The duck was then kept in a metabolic chamber for energetic measurements and at the end of the experiment (lasting several hours), its faeces were collected. From these, all fragments that could be related to original shell size were sorted and the measurements as outlined above were taken. As the size of the prey was known, we could determine the reliability of the procedure of back-calculating prey size from faecal fragments.

These experiments were not repeated with *Ensis* as prey, as it was felt that force-feeding *Ensis* could be hazardous for the birds (see: Swennen & Duiven 1989).

Field samples

***Spisula*: scoter stomachs**

Stomachs were taken from oiled Common (n=23) and Velvet Scoters *M. fusca* (n=2), beached near a major *Spisula* bank off Terschelling in January 1995. These stomachs had been dissected out of the birds shortly after they were found and kept frozen until analysis. The stomachs were thawed for the present study and

rinsed with tap water to flush out all shell fragments. Samples were dried and *Spisula* shell fragments from which shell thickness measurements could be taken (no hinges were found) were sorted under a binocular microscope.

***Ensis*: Eider faeces**

In December 2001 and in February 2003, Eider faeces were collected at the 'Razende Bol', a sandbank off Texel in the Dutch North Sea (52°58.50'N, 04°41.30'E). Here several thousands of Eiders were resting during high tide at the time. A total of 47 (2001) and 45 (2003) individual dropping were collected and kept frozen in plastic bags until analysis. After thawing, the faeces were washed and the shell fragments were sorted under a binocular microscope. The different species of prey present in the faeces were identified by comparison to a reference collection of shells. *Spisula* fragments were rare in this material, and no hinges of this species were found. The bulk of the shell fragments were *Ensis* and from each sample the thickest and thinnest shell fragment that could be found were sorted out, as well as 8 randomly chosen fragments, and the thickness of these 10 fragments were measured.

Results

***Spisula* feeding trials with captive Eiders**

A total of 239 *Spisula* were fed to the ducks in the feeding trials. From the 478 hinge-halves that were thus potentially available, not a single one was recovered intact from the faeces. Only bits and pieces were found, like parts with one groove, tooth or chondrophore. Furthermore, most grooves and cardinal and lateral teeth were too damaged to be measured accurately (cf Dekinga & Piersma 1993). In total, 55 measurable parts (11.5 %) were recovered, from which 77 measurements were taken. In addition to the hinges, a total of 109 shell fragments were retrieved from the faeces, in which shell thickness could be measured at one of the pre-identified reference points (see Figure 4.2).

***Spisula* hinges**

In total, 10 diagonal lengths (#1 in Figure 4.1) and 12 heights (#2) from 12 chondrophores from right valves and 14 diagonal lengths (#5) and 16 heights (#6) from 18 chondrophores from left valves could be measured. From 11 fragments the distance between the two cardinal teeth (#7) could be measured, while also the lengths of 8 anterior lateral teeth (#8) and of 6 posterior lateral teeth (#9) could be taken. The chondrophores were thus the parts most frequently recovered in a measurable state. Even so, of all chondrophores of the *Spisula* fed to the ducks, only 5.9 % were recovered (28 out of 478). For the cardinal teeth this percentage was 4.6, while only 2.9 % of the lateral teeth were recovered in such a state that they could be measured.

As the true sizes of the *Spisula* fed to the ducks were known, it was possible to calculate the errors that resulted from estimating shell size from the hinge measurements. Precision of any one estimate was rather low, and shell lengths could be underestimated by as much as 33.4% or overestimated by 26.0% (Table 4.5, Figure 4.4). The chondrophore measurements provided slightly better estimates than the cardinal and lateral teeth, as the overall bias was smaller. More important-

Table 4.5 Analysis of under- and overestimates (errors) of shell sizes estimated from different measures on hinge fragments found in faeces of Common Eiders *Somateria mollissima*, fed with *Spisula subtruncata* of known size. For measures (first column): see Figure 4.1.

Measure	AVG-%-error	range of errors	s.e.	N
#1 chondrophore diagonal length right valve	–4.0	–12.9 to 19.0 %	3.04	10
#2 chondrophore maximal height right valve	–3.9	–21.3 to 9.5 %	2.57	12
#5 chondrophore diagonal length left valve	3.4	–11.4 to 26.0 %	2.76	14
#6 chondrophore maximal height left valve	1.4	–19.1 to 17.5 %	2.32	16
#7 distance between the cardinal teeth	–7.7	–33.4 to 18.2 %	4.72	11
#8 length of anterior lateral tooth	–9.1	–19.3 to –1.4 %	2.46	8
#9 length of posterior lateral tooth	0.9	–16.2 to 17.2 %	5.20	6
Total	–2.2	–33.4 to 26.0 %	1.27	77
Total for chondrophores only	–0.3	–21.3 to 26.0 %	1.36	52

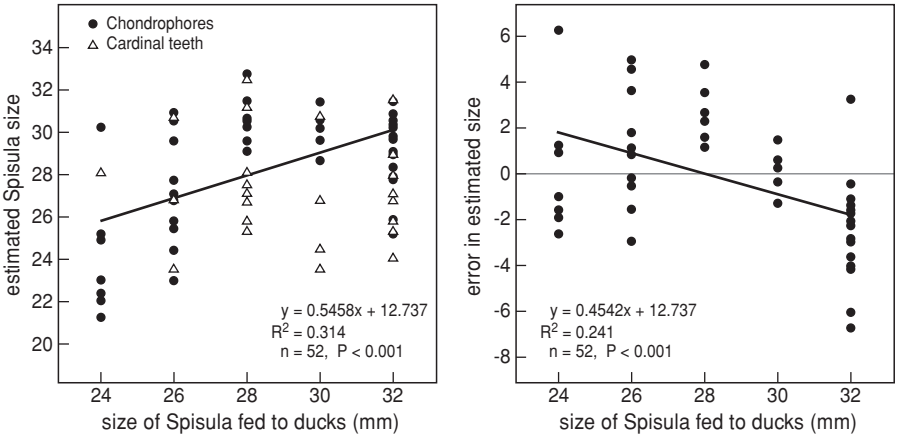

Figure 4.4 Estimated size of *Spisula subtruncata* as based on hinge-measurements, as a function of true shell size as fed to Common Eiders *Somateria mollissima* in the feeding experiments (left). A regression line is only given for chondrophore measurements (closed symbols; measurements #1-6 combined) as the measurements from the cardinal teeth (open symbols; measurements #7-9 combined) did not yield a significant correlation. Right panel: errors associated with the estimates (from chondrophores only) as: estimate–true size.

ly, over the size range studied here, there was no relationship between true shell size and shell size as estimated from the cardinal and lateral teeth, while this relationship was highly significant when chondrophore measurements were used (Figure 4.4). However, sample sizes were quite low and when all possible estimates were considered together, errors appeared to be distributed rather symmetrically, resulting in an average underestimate of shell size by only 2.2%. When only the chondrophores are considered, the average error is only –0.3%. It appears therefore, that the sizes of individual *Spisula* eaten by Eiders cannot be estimated with great reliability from hinges in faecal material, but if a sufficient number of hinges (hinge parts) can be obtained, the average size of the ingested prey can be estimated quite well, particularly from the chondrophores.

Spisula shell thickness

Shell length was also estimated from 109 shell fragments retrieved from the faeces, in which shell thickness could be measured at one of the pre-identified reference points (see Figure 4.2). Combining all measurements, a significant relationship was found between estimated shell size and true shell size (Figure 4.5). Errors again showed a negative relationship with true shell size, indicating that sizes of small *Spisula* were overestimated, while sizes of large *Spisula* were underestimated (Figure 4.5, right panel). Overall, the estimated sizes were more or less correct with an average error of only –0.76%, but with individual estimates being anywhere from –26 to +34% off (Table 4.6).

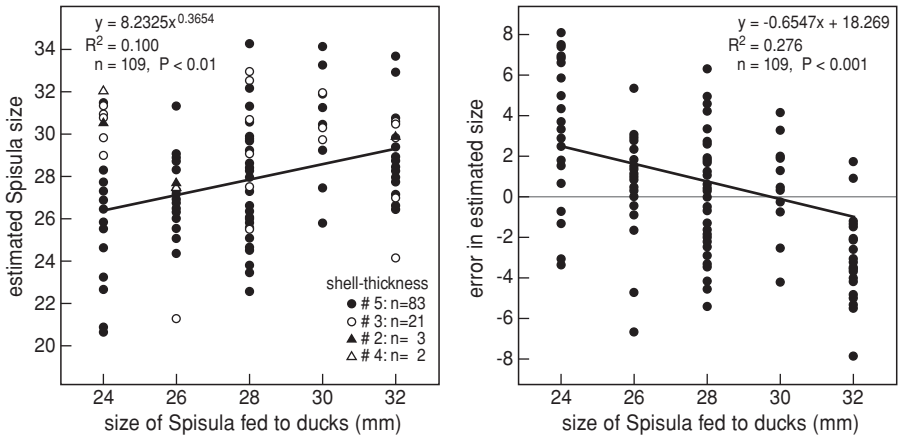

Figure 4.5 Estimated size of *Spisula subtruncata* as based on shell thickness measurements, as a function of true shell size as fed to the Common Eiders *Somateria mollissima* in the feeding experiments (left). The regression line is for all measurements combined. Right panel: errors associated with the estimates as: estimate–true size.

Table 4.6 Analysis of under- and overestimates (errors) of shell sizes estimated from different measures of shell thickness of fragments found in faeces, of Common Eiders *Somateria mollissima* fed with *Spisula subtruncata* of known size. For measures (first column): see Figure 4.2.

Measure	AVG-%-error	range of errors	s.e.	N
#2 PAM	9.2	–6.7 to 27.6 %	9.96	3
#3 Ventral PL	4.2	–24.7 to 30.5 %	3.59	21
#4 AAM	19.6	5.7 to 33.6 %	13.95	2
#5 Outer rim	–0.9	–25.8 to 31.1 %	1.19	83
Total	–0.76	–25.8 to 33.6 %	1.22	109

Spisula in scoter stomachs

Spisula remains were found in six stomachs of oiled Common Scoters and in one Velvet Scoter, beached at Terschelling in January 1995. No shell fragments with measurable hinges were present, but shell thickness measurements could be taken from a total of 31 shell fragments. At the time when the ducks beached, the Dutch coastal waters were surveyed for *Spisula subtruncata* and sea duck. Off Terschelling 50,000 Common Scoters and 1200 Velvet Scoters were found, as well as high *Spisula* densities (Leopold 1996). In 61 Van Veen bottom grabs taken off this island, 676 *Spisula* were found, mostly belonging to a single year-class (14–21 mm shell length). Very few *Spisula* of older year classes were found, but in the stomachs, *Spisula* of several year classes, including older ones, were found according to the reconstructed sizes from the shell thickness measurements (Figure 4.6). Note, however, that *Spisula* of around 20 mm shell length may be overestimated by some 5 mm from shell thickness measurements (Figure 4.5). Still, there is a suggestion that *Spisula* of 25–30 mm were taken disproportionably often by the ducks.

Ensis as Eider prey

Size distribution of *Ensis* available to Eiders roosting on the Razende Bol was determined in the same winters when the faeces were collected, by using a Van Veen bottom grab in nearshore waters off Texel, some 14 km north of the roost (Leopold 2002b, 2003). Although this grab may have missed some of the larger *Ensis* that have a higher probability to escape from this sampling device (Leopold 2002b), it is clear that in winter 2001/02 0-group *Ensis* (animals <65 mm long) dominated the population, while 0-group and 1-group animals (>65 <110 mm long) were present in more or less similar numbers in 2002/03 (Figure 4.7). *Ensis* was the dominant species in both winters, comprising 55% of bivalve biomass in 2002 and 95% in 2003. In the first winter a considerable proportion of the bivalve biomass was made up by Donax (26%) and *Macoma* (10%), but *Ensis* was apparently selected as food by the Eiders, as this was relatively more commonly present in the faeces (Table 4.7).

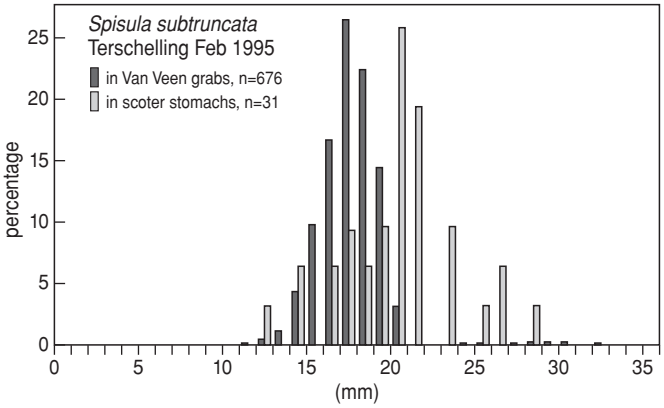

Figure 4.6 Size-frequency distributions of *Spisula subtruncata*, present off Terschelling in February 1995 (dark grey bars), compared to estimated sizes of *Spisula subtruncata* found in Common Scoter *Melanitta nigra* stomachs (light grey bars). A total of 29 sizes of ingested *Spisula* were derived from shell fragments found in Common Scoter stomachs and two more (24.3 and 25.6 mm estimated shell length, included in the graph) were found in a Velvet Scoter *Melanitta fusca*. Note that the apparent difference between the peaks in the two length distributions (at 18 and 21 mm respectively) was probably caused by overestimation of shell size from shell fragment thickness measurements (see Figure 4.5).

The faecal samples collected on the Razende Bol in December 2001 and in February 2003 contained 9 prey species in total, with *Ensis americanus* as the dominant prey species, in either winter (Table 4.7). In both winters combined, *Ensis americanus* was present in 87 out of 92 droppings (94.7%) and 78.3 % of the samples contained *Ensis* exclusively. *Spisula* remains were present in only 5 of the 92 samples and no measurable parts were found that could be used to estimate original shell length. Several other prey species were also identified in the faeces, but like *Spisula*, their contribution was marginal (Table 4.7).

Ensis hinges

Ensis hinges or parts of hinges were found in 12 of the 47 faecal samples collected in December 2001 and in 25 of the 45 samples collected in February 2003 (Figure 4.7). The left and right halves of the hinges were usually separated in these samples, making an estimation of total numbers of prey animals involved not possible. Measurements could be taken from 43 and 59 parts (left or right summed), for the first and second winter samples, respectively. As often more than one measurement per hinge-half could be taken, total numbers of measurements amounted to 188 (Table 4.8), for 102 hinge-halves. If more than one measurement for a given hinge-half could be taken, we used the average estimate for all these measurements as the final estimate for shell size (Figure 4.7).

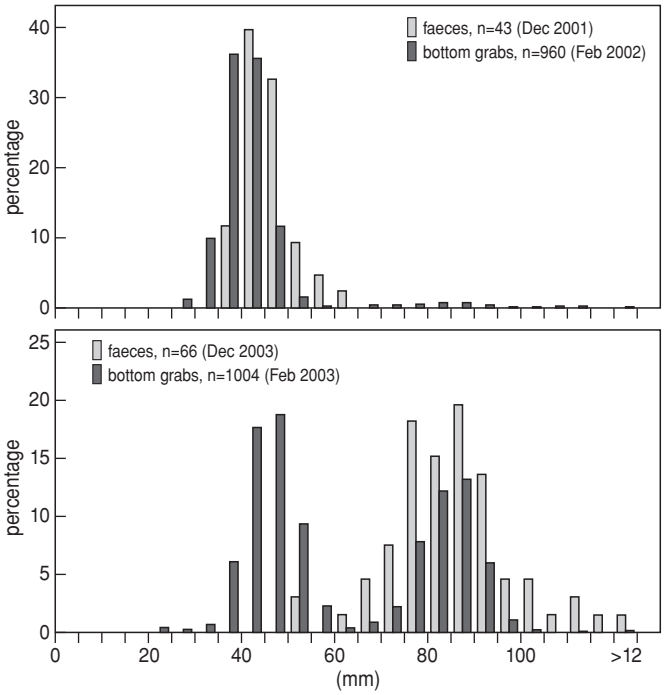

Figure 4.7 Length-frequency distributions of *Ensis americanus* as reconstructed from hinges in Common Eider *Somateria mollissima* faeces collected at the Razende Bol in December 2001(upper panel) and in February 2003 (lower panel), compared to sizes of *Ensis* found in bottom samples near the roost (dark grey bars) in the same winters. No growth is thought to occur in shellfish in midwinter, i.e. between December 2001 and February 2002. Shell lengths in mm, in 5 mm bins.

Table 4.7 Occurrence of different prey species in Common Eiders *Somateria mollissima* faecal samples collected in the field (Razende Bol) in two successive winters. 47 faeces were collected on 11-12-2001 and 45 on 26-02-2003. The numbers of samples containing each of the prey species are given.

Prey species	Dec 2001	Feb 2003	Total
Ensis americanus	45	42	87
Carcinus maenas	7	0	7
Mytilus edulis	0	5	5
Spisula subtruncata	4	1	5
Littorina littorea	2	0	2
Macoma balthica	1	0	1
Cerastoderma edule	1	0	1
Donax vittatus	0	1	1
Natica alderi	0	1	1

Shell lengths of *Ensis* were estimated using the equations given in Table 4.3. All *Ensis* taken in December 2001 probably were 0-group animals, with predicted lengths ranging from 40.9 to 64.4 mm. Reconstructed sizes of *Ensis* for February 2003 ranged from 52.6 to 139.8 mm and comprised three year classes (Figure 4.7). Presumed 1-group *Ensis* (n=53), with lengths from 65–110 mm predominated. Only two smaller *Ensis* were found (53 and 54 mm) and four *Ensis* with reconstructed shell lengths of 113-140 mm.

Sizes of 1-group *Ensis* present in the seabed and taken by the Eiders in February 2003 were not statistically different (Table 4.8, t-test, NS). However, the reconstructed shell lengths of the 0-group *Ensis* taken in December 2001 were some 5 mm larger than the lengths of the same animals sampled at sea two months later, in February 2002 (Table 4.8, $t=5.88$, $P<0.01$). The shape of the size distribution of *Ensis* present in the seabed and of *Ensis* found in the faeces is very similar, with an offset of 5mm (Figure 4.7). This suggests that the difference should not be attributed to selective sampling (either through size selection by the birds or by selectively missing relatively large *Ensis* in the grab samples). More likely, a systematic error was involved in estimating the size of these small 0-group *Ensis* from the hinges still present in the faeces. Without a feeding experiment in which sizes of prey fed to the birds are known (like in our experiments with *Spisula*), this cannot be further explored.

If we compare the estimates of *Ensis* shell length (Table 4.8) as derived from different parts of the hinge to the presumed "ground truth" (the average sizes of *Ensis* in the grab samples in either winter), we see that measurement #5 (IF = maximum length in right valve, see Table 4.3 and Figure 4.3) gives the best estimates of original shell length, in both year classes. All other measurements resulted in overestimates in the 0-group *Ensis*, and in more varied errors in the 1-group.

Table 4.8 Average lengths (with SD and sample size) of the dominant age group of *Ensis americanus* in Van Veen bottom grabs taken off Texel in two consecutive winters compared to average lengths of *Ensis* found in Common Eiders *Somateria mollissima* faeces at the Razende Bol roost, as reconstructed from the hinges present therein. All specimens smaller than 65 mm were considered to be 0-group *Ensis* (see Figure 8) and all specimen between 65 and 110 mm were considered to be 1-group. For measurements #2-7 see Figure 4.3 and Table 4.3.

		Bottom grabs	#2 (A-B)	#4 (C-D)	#5 (I-F)	#6 (I-H)	#7 (E-G)	**Average est. prey size**
0-group:	Avg	**40.21**	45.09	49.49	41.80	46.57	46.94	**45.42**
Feb 2002	SD	**4.51**	4.40	4.90	5.55	4.80	7.84	**5.73**
	N	**923**	13	8	30	38	15	**43**
1-group:	Avg	**84.08**	80.01	94.01	82.54	81.82	89.95	**84.80**
Feb 2003	SD	**6.29**	6.58	12.21	6.41	11.34	15.79	**8.63**
	N	**438**	24	24	7	18	11	**53**

Ensis shell thickness

From each sample that contained *Ensis* the thickest fragment was sorted out, as well as an anterior (thinnest) fragment and their thicknesses measured. Eight more randomly selected fragments per sample were sorted out and measured. For using this procedure, it had to be assumed that all *Ensis* in one sample were of the same size. Finding the thickest fragments from the faeces proved to be relatively easy, since these were generally the largest parts present. Sorting out the thinnest parts was sometimes a problem, since these parts were often severely fragmented.

Shell lengths of *Ensis* were estimated using the equations given in Table 4.4. The predicted lengths of *Ensis* for December 2001 ranged from 44.7 to 79.6 mm and from 65.8 to 107.8 mm for February 2003. Figure 4.8 depicts the frequency distributions of estimated shell lengths. The three estimation procedures produced similar results. 0-group *Ensis* was predominantly taken by the Eiders in December 2001 and one year olds in the next winter (Figure 4.8). However, shell size was overestimated when compared to the average sizes of 0-group and 1-group *Ensis* in the grab samples in either year (Table 4.8). Possibly, relatively thick shell parts (within or between shells) were better preserved in the faeces, resulting in a positive bias of 1.5 to 2.1 cm (37–53%) for the 0-group *Ensis* and of 0.2 to 1.0 cm (2–12%) for the 1-group (Tables 8 and 9).

Discussion

Prey identification

Sea ducks such as eiders or scoters ingest their prey whole and crush these in their muscular gizzards. Remaining shell fragments in stomachs or faeces provide clues on the prey species taken. Eiders and scoters mostly feed on hard-shelled molluscs (Leopold *et al.* 2001a, Fox 2003) that always leave such clues. Other prey such as crabs, worms or fish also contain hard parts that may be identified and only very rarely soft prey such as fish eggs will be taken (e.g. Gjøsæter & Sætre 1974, Bishop & Green 2001) that may be overlooked for the lack of suitable hard parts. From Eiders, faecal samples can be collected with relative ease and these can be processed rather quickly. Scoters rest at sea, and collecting scoter faeces seems impossible. Good field material may, however, also be obtained from stomachs, from shot, drowned or oiled birds and good opportunities to use such material should always be considered.

In samples collected in the field, prey species composition is *a priori* unknown, as opposed to the situation in our cage experiments. In most field studies however, some understanding of local prey availability is usually available, aiding identification of shell fragments. In situations where ducks are likely to feed on one superabundant prey organism, as has been be situation in the SE North Sea lately, the prey may be easily identified. However, sea ducks may also feed in habitats with a

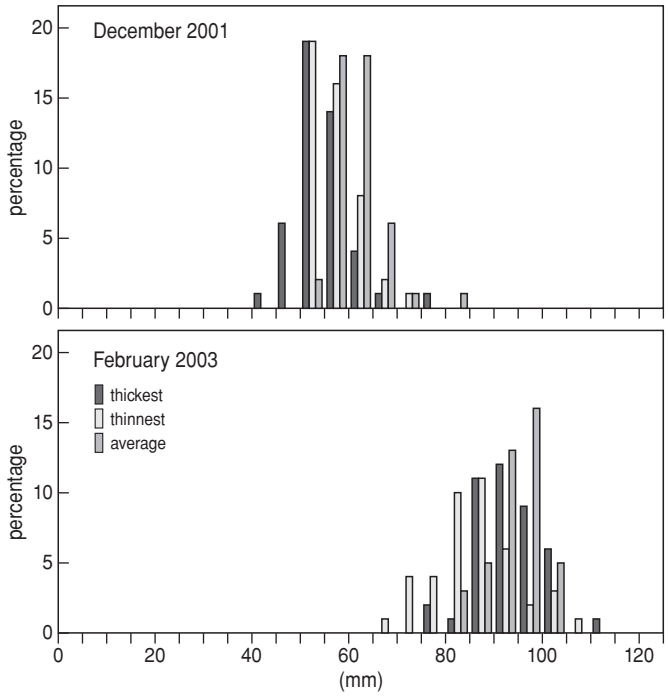

Figure 4.8 Estimated sizes (shell lengths, mm) of *Ensis americanus* taken as prey by Common Eiders *Somateria mollissima* resting on the Razende Bol in winter 2001/02 and in winter 2002/03. Shell lengths are estimated from the thickest fragment in each faecal sample, from the thinnest and from these plus 8 randomly taken fragments per sample (average).

much larger diversity of prey (*cf* Aulert & Sylvand 1997, Hughes *et al.* 1997, Thingstad *et al.* 2000, Rumohr 2002) and this could make identification of shell fragments more complex. In our own samples of eider faeces we found seven prey species, but one (*Ensis americanus*) was clearly the staple food.

Recognizing *Spisula* and *Ensis* fragments in sea duck stomachs or faeces proved to be rather straightforward. *Spisula* fragments are thick, and have a whitish inside and a light brown, rough outer surface with fine parallel lines. The shells are not clearly ridged like in *Cerastoderma* sp. (that are also much whiter and thicker). *Donax vittatus* shells are shiny brown on the outside without the fine lines that mark *Spisula*, and purple on the inside. The hinges of *Spisula* differ from those of Donax, by the presence of two lateral teeth on the left valve (and matching grooves on the right valve, Figure 4.1) and by having a chondrophore filled with a brown internal ligament. Donax lacks these features. *Spisula* hinges resemble those of the closely related *Mactra corallina*, but these shells are much thinner and their inside is purple, not white. *Ensis* is purple to pinkish-white on the inside and has a brownish skin on the outside of the valves. *Ensis* shell fragments are clearly thinner

than those of *Spisula* and much smoother. The purple to pink shells of *Mactra* are usually much darker than *Ensis* and lack an outer layer of skin as is present on *Ensis*. Some *Macoma balthica* are also pink but are so at both sides and these shells come in all sorts of bright colours, preventing misidentifications. Fragments of other bivalves like *Tellina* or *Abra* that may have been taken by scoters in Belgium waters (Degraer *et al.* 1999) superficially resemble *Spisula* or *Ensis* fragments, but are in fact different in both colour and texture. Mussel fragments are blackish blue and very different from *Spisula* or *Ensis*. *Mya* sp. are also important sea duck prey, particularly in the Baltic (Kirchhoff 1979, Stempniewicz 1986, Meissner & Bräger 1990, Kube 1996, Rumohr 2002, Žydelis 2002). *Mya* sp. are but is whiter than both *Spisula* and *Ensis* and have very different hinges. Shore crabs may be similar in coloration to both *Spisula* and *Ensis*, but are always given away by their claws that are their hardest parts.

Eiders and scoters take different *Spisula* species and razor clams in other parts of their range (see e.g. Stott *et al.* 1973, Hughes *et al.* 1997, Rumohr 2002) and identification could be more problematic if several similar species are taken simultaneously. Clearly, knowledge of the local benthic fauna helps to correctly identify badly broken-up prey remains. More information is needed on such prey species, but clearly, the methods presented in the current paper could also applied to these, or any other prey species with hard remains. Furthermore, using these methods is not necessarily restricted to seaduck studies, but could also be used on other animals that ingest shellfish whole, such as gulls (see e.g. Meijering 1954, Löhmer & Vauk 1969, Vauk & Löhmer 1969, Spaans 1970, Wietfeld 1977, Garthe *et al.* 1999, 2003, Kubetzki & Garthe 2003), waders (e.g. Dekinga & Piersma 1993, Scheiffarth G. 2001), or fish (Arntz 1972, Braber & de Groot 1973).

Estimation of prey numbers ingested

The number of measurable hinges that could be sorted out of the stomachs or faeces was low. No useful hinge-parts could be retrieved from 25 scoter stomachs. None were recovered intact from the faeces in our feeding experiments, only 55 bits and pieces were found after digestion and excretion of 239 *Spisula* (11.5 % of all available hinge-halves). From these 55 hinge-parts, 77 measurements could still be taken, mostly (n=52, Table 4.5) from the chondrophores. From the same 239 *Spisula* a total of 83 fragments from the outer rim were retrieved from the faeces (Table 4.6) that were suitable for thickness measurements, suggesting a slightly higher (17 %) recovery rate. However, since it cannot be excluded that more than one fragment per valve was measured, actual recovery rate was probably somewhat lower. The shells of *Spisula* appear to be quite brittle, and are crushed to small fragments in the ducks stomachs, destroying most measurable parts (cf Dekinga & Piersma 1993). *Ensis* provided even lower recovery rates. In our 92 Eider scats we found a total of 102 *Ensis* hinge-halves, with no clues that could be used to match left and right halves. Even if these 102 hinge-halves were from 102 different *Ensis*,

this would only represent about 1 razor clam per scat. Thickness measurements could not provide a better estimate of number of prey represented in a scat, as we used minimum, maximum or average values per scat (i.e. n=1). Field studies using faeces are, in any case unlikely to be of much use for direct estimations of numbers of prey ingested by birds that defecate many times a day. Thus, single scats only contain remnants of a fraction of the prey ingested during a day.

Prey size estimation

Based on both the feeding experiments and the field studies, we feel confident that the general size class (or age class) of both *Spisula* and *Ensis* was estimated correctly. However, within the size range of prey taken by eiders and scoters, sizes of small *Spisula* were overestimated, while sizes of large *Spisula* were underestimated, by about 2–5 mm on average (Figures 4.4, 4.5 and 4.6). Maximum errors for individual shells were about 8 mm (33%, Tables 4.5 and 4.6), these amounts of error were similar for reconstructions based on hinge and shell thickness measurements.

Based on field study comparisons, small, 0-group *Ensis*, of circa 40 mm length were over estimated by about 5 mm and 1-group *Ensis* of circa 84 mm by less than 1 mm in eider faeces, when hinges were used for reconstruction (Table 4.8). These errors were larger when shell thickness was used (positive biases of 15–21 mm in 0-group, and 2–10 mm in 1 group *Ensis*, respectively, Table 4.9). Still, again the dominant size (age) group was probably identified correctly in our eider faeces.

If a mixture of more than one year class of *Ensis* is ingested, using shell thickness will provide less accurate results. In contrast to *Spisula* in which particular parts of the inner shell could still be pinpointed in the fragments, we could only work with one (average or minimum or maximum) value per sample in *Ensis*. The fact that the faecal samples of the first winter showed a positive bias for estimated prey size could thus indicate that some 1-group *Ensis* were also taken, with a majority of 0-group prey. Some 1-group *Ensis* were present in the benthic samples,

Table 4.9 Average lengths (with SD and sample size) of *Ensis americanus* taken by Common Eiders *Somateria mollissima* off Texel, as reconstructed from the thickness of shell fragments present in their faeces collected at the Razende Bol roost. For measurements see Figure 4.2.

		Thickest part	Thinnest part	All ten parts
December 2001	Avg	55.20	57.14	61.44
	SD	5.58	4.32	4.81
	N	46	46	46
1-group: Feb 2003	Avg	93.21	86.07	94.34
	SD	7.22	9.34	5.17
	N	42	42	42

and if the ducks showed a strong preference for these larger preys, such a bias in estimated sizes could occur. Alternatively, a positive bias of ingested prey sizes may also occur if the probability of retrieving measurable shell fragments increases with shell size. There is also some evidence in support of the latter hypothesis. Given that smaller prey should be taken in larger quantities than larger prey, larger numbers of *Ensis* should have been found in the first winter samples when mainly 0-group *Ensis* were available. The opposite was found (Figure 4.7, Table 4.8), suggesting that many of 0-group *Ensis* hinges got broken to such an extent in the ducks' stomach that they could not be retrieved from the faeces.

Is the method accurate enough to study prey size selection by sea duck?
Fox (2003) has commented that: prey selection in Common Scoter has still to be demonstrated, as data on sizes of ingested prey and prey sizes available for ingestion in field situations have never been studied simultaneously. He also noted that scoters have been recorded to feed on a wide size range, and suggested that scoters may not be very selective when it comes to prey size. This suggestion is corroborated by the results of Durinck *et al.* (1990), who found the same sizes of ingested *Spisula subtruncata* in Common Scoters and the larger Velvet Scoters that were drowned in the same bottom set-nets, indicating that both species of sea duck simply took what was locally available. In contrast, many studies on the feeding ecology of Common Eiders (summarized in Leopold *et al.* 2001a) have shown that these ducks are selective, taking mussel sizes with the highest energy return, or prefer small or thin-shelled individuals or mussels with relatively few barnacles growing on their shells.

In our own work on *Ensis*-eating eiders, we unknowingly studied a situation in which mainly 0-group *Ensis* was available to –and taken by- the ducks in one winter, while both 0-group and 1-group *Ensis* was available in the next winter. When given this choice, the birds clearly selected the larger, 1-group prey, *Ensis* of 8–9 cm long (Figure 4.7). There is some evidence, both from direct observations and from stomach analyses, that eiders and scoters are capable of eating even larger *Ensis*, but as yet, optimal or maximum sizes (or indeed dangerous sizes) are not yet known.

Our small data set from stomach contents of scoters (Figure 4.6) suggests that they too, showed size selection. These ducks were feeding on a rich *Spisula* stand that was mainly composed of 14–21 mm long individuals. Although these were probably also mostly taken by the scoters, we found evidence that larger (older) *Spisula* of 25–30 mm were taken disproportionably often (Figure 4.6). According to Fox (2003) this is the first evidence for size selection in scoters.

Our study presents the first evidence for size selection in Common Eiders feeding on a new prey species, the American Razor Clam. Perhaps surprisingly, the eiders took relatively large *Ensis* when given the choice. Apparently, the better energy return out weighted the risk of injury in 1-group *Ensis* compared to 0-group

razor clams. In both situations, the *Ensis* was the staple food of the eiders, in a situation when the traditional prey species (blue mussel, edible cockle and *Spisula*) were in short supply. In the winters of 2001/02 and 2002/03 when our study was conducted, the *Spisula* stocks had just collapsed in the Netherlands, while stocks of mussels and cockles in the Wadden Sea were also very low. Tens of thousands of Common Eiders had died of starvation during the preceding winter (Camphuysen *et al.* 2001) and the ducks were hard-pressed to switch to alternative prey. *Ensis americanus* has colonized the eastern North Seaboard very successfully, and both eiders (this study) and scoters (Leopold & Wolf 2003, Wolf & Meininger 2004) have now learned to utilize this rather awkwardly shaped shellfish to their advantage.

Acknowledgements

Gerhard Cadée supplied us with a range of reference *Ensis* shells. Janne Ouwehand provided the drawing of the *Ensis* hinge as depicted in Fig. 4.3. Piet van der Hout lent us his shell thickness micrometer and Katja Philippart and Jolanda van Iperen allowed and instructed us to use the Zeiss Microscope, digital camera and software. Hessel Wiegman surprised us on board our research vessel during a benthic cruise when he brought us 25 oiled, dead scoters that we later used in this study. The skippers and crews of RVs Navicula, Smal Agt, Phoca, Stormvogel, Cornelis Bos and Isis are thanked for their assistance during many benthic surveys and (Navicula and Phoca) extra trips to collect eider faeces.

The Eiders were kept under licence #Alt.2002.10 (RK) of the Animal Ethics Committee of the Royal Dutch Academy of Sciences (KNAW). Housing, continuous water supply and daily care were provided by Piet Wim van Leeuwen, Rogier van Viegen, Annemarie Teunissen and Aad Sleutel. The ducks were fed with live *Spisula subtruncata* and *Mytilus edulis*, provided by the crews of several research and inspection vessels of the Ministry of Agriculture, Nature and Food Quality (LNV), and Tanya Compton (NIOZ). This research project was supported by grants from LNV and the Netherlands Organisation for Scientific Research (NWO).


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