The diet of New Zealand King Shags (*Leucocarbo caruncuiatus*) in Pelorus Sound

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ABSTRACT

The diet of New Zealand King Shags (*Leucocarbo carunculatus*) in Pelorus Sound, South Island, New Zealand, was deduced from diagnostic prey remains in 22 complete regurgitated pellets collected as two samples taken six months apart. Pellets represented a total of about 683 prey items with an estimated wet mass of 14.9 kg. Witch (*Arnoglossus scapha*), a lefteyed flatfish (Bothidae), dominated the diet and accounted for about 90% of prey items and 95% of wet mass in both samples, but there was a change in the average size taken. The average total wet weight per pellet matched the theoretical estimate for daily energy expenditure for the shags. Prey species of interest to commercial or recreational fishers accounted for only 1-3% of the diet. These results are applicable only to the 25% of the species total population that forages in Pelorus Sound. An investigation of the diet elsewhere in Marlborough Sounds is recommended in order to determine if the small population size and restricted distribution of King Shags are related to the availability of food.

KEYWORDS: New Zealand King Shag, *Leucocarbo carunculatus*, *Arnoglossus scapha*, otoliths, daily food intake.

INTRODUCTION

New Zealand King Shags (*Leucocarbo carunculatus*) total only about 500 individuals with a distribution restricted to Marlborough Sounds (41° S, 174° E), South Island, New Zealand (Nelson 1971, Schuckard 1994). Fossil bones from the far north of North Island indicate that their range contracted after the arrival of Polynesians in New Zealand (Worthy 1996). However, records stretching back to 1773 suggest that King Shags have been neither more numerous nor more widespread through the historical past (Nelson 1971). Present knowledge of their diet is based on incidental observations of regurgitations at breeding colonies and the stomach contents of shot birds and indicates that King Shags hunt bottom-dwelling fish (Nelson 1971).

A structural diet study of a species as rare as the King Shag must employ methods that neither kill nor adversely disturb birds. The analysis of regurgitated pellets has gained broad acceptance as a non-destructive sampling method to quantify the diets of shags, but can produce biased results (Barrett *et al.* 1990). Prey that lack indigestible hard parts are likely to be under-represented. Also, the digestive erosion of otoliths, the diagnostic remains of fish, can result in underestimates of the numbers and sizes of the fish that they represent. Stewart Island Shags (*L.*

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chalconotus), the congeneric South Island relative of King Shags, daily regurgitate one pellet of undigested prey remains enclosed in a mucous sac (Lalas 1983). In contrast to eroded otoliths from pellets of some *Phalacrocorax* species of shags (Barrett *et al.* 1990), practically all otoliths from pellets of Stewart Island Shags are pristine (Lalas 1983).

Here we analyse regurgitated pellets to give an insight into the diet of King Shags from samples six months apart at one site. Our study site was at Pelorus Sound where one-quarter of the population total of King Shags forage diurnally in water 10-50 m deep (Schuckard 1994). From this pilot study we can determine the logistics for a comprehensive study of temporal and spatial patterns in diet.

METHODS

We analysed 22 complete and fresh regurgitated pellets from a King Shag roost at Te Kaiangapipi (41° 01' S, 173° 56' E), a mainland promontory in the Waitata Reach of Pelorus Sound. Twelve pellets were collected on 14 November 1991 and 10 on 6 May 1992. The numbers of shags at this roost varied diurnally (DB, pers. obs.), with least ashore through the middle of the day. We minimised disturbance by collecting pellets at this time.

Only fresh pellets with the mucous coating still moist were collected. This restriction ensured that the contents represented prey consumed recently, probably through the previous day. Each pellet was placed into a separate plastic bag and all pellets subsequently analysed were deemed to be intact and complete, as far as could be determined by visual inspection. Pellets were initially frozen to prevent deterioration, then dried in the warming tray of a conventional oven before forwarding to Portobello Marine Laboratory, University of Otago. Here pellets were teased apart under water and the contents sorted. Crustaceans were identified to genus from exoskeletal remains and fish to genus (or to species for monospecific genera) from otoliths by comparisons against a reference collection held by CL. These diagnostic remains were dried and stored in plastic bags. The duration of analysis (sorting, measuring and documentation), averaged about 5 h per pellet. Estimates for the sizes of witch (*Arnoglossus scapha*), a lefteyed flatfish (Bothidae), represented by otoliths in pellets were derived from otoliths in fish retrieved from catches by factory trawlers fishing around the northern half of South Island from August to November in 1994 and 1995. Exponential equations to back-calculate the total length (*TL*, mm) and the wet mass (*FM*, g) of witch were deduced from the mass of the pair of sagittal otoliths (*OM*, mg):

$$TL = 45.47\ (OM)^{0.463} \quad r^2 = 0.900,\ n = 81,\ p < 0.001$$
$$FM = 0.279\ (OM)^{1.624} \quad r^2 = 0.917,\ n = 81,\ p < 0.001$$

Estimates for the original sizes of other prey items were calculated using species-specific equations for crustaceans and fish from southern South Island (Lalas 1983). Fish lengths presented in diet analyses were rounded down to the nearest cm following standard fisheries practice. One-tailed Student's *t*-tests were used to check for the statistical significance of differences between means. Bird names follow Turbott (1990) and fish names and systematic listing follow Paulin *et al.* (1989).

TABLE 1 - Systematic listing of prey species of King Shags roosting at Te Kaiangapipi, Pelorus Sound.

	14 November 1991			6 May 1992		
Prey	Occurrence in % of pellets	Relative frequency as prey, %	% wet mass	Occurrence in % of pellets	Relative frequency as prey, %	% wet mass
Crabs						
Portunidae (swimming crabs)						
Nectocarcinus sp. red swimming crab	33	<1	<1	10	<1	<1
Hymenosomidae (penny crabs)						
Unidentified crab, 1 sp.	8	<1	<1	0	0	0
Fish						
Percophididae (opalfishes)						
Hemerocoetes opalfish 2 spp.	67	4	1	80	7	1
Tripterygiidae (triplefins)						
Forsterygion ? triplefin sp.	25	<1	<1	20	1	<1
Bothidae (lefteyed flounders)						
Arnoglossus scapha, witch	100	91	94	100	90	97
Pleuronectidae, (righteyed flounders)						
Pelotretis flavilatus, lemon Sole	33	2	0	0	0	0
Peltorhamphus sole sp.	33	1	<1	20	2	<1
Rhombosolea, flounder sp.	8	<1	<1	10	<1	1
Unidentified fish, 2 spp.	17	<1	est. 1	0	0	0
Sample sizes	12 pellets	497 items	~7.9 kg	10 pellets	186 items	7.0 kg

RESULTS

Prey species

The 22 complete regurgitated pellets analysed contained remains of about 683 prey items with an estimated total wet mass of 14.9 kg (Table 1). They represented two genera of crustaceans and eight genera of fish. Fish otoliths and skeletal remains were found in every pellet. Exoskeletal remains of crustaceans were found in five of the 12 pellets collected on 14 November 1991 and one of the 10 pellets collected on 6 May 1992.

Witch dominated the diet and accounted for about 90% of the total prey items and 95% of the total wet mass represented in regurgitated pellets on both sampling dates. The combination of three genera of righteyed flatfishes (Pleuronectidae) accounted for 1-3% by number and by wet mass of prey items. Other than flatfishes, the only prey that appeared regularly were opalfishes (Percophididae), which overall accounted for about 5% by number and 1% by mass of prey items. Tentative identifications of the opalfish otoliths indicated a mixture of two species: *Hemerocoetes monopterygius* and *H. pauciradiatus*. Triplefins (Tripterygiidae) were identified only tentatively to genus because not only is their taxonomy "confused" (Paulin *et al.* 1989), but also most species cannot be differentiated by otoliths (CL unpubl. data). A lack of sufficient reference material precluded the positive identification of the otoliths of seven fish representing two species from 14 November 1991. Although entered as "unidentified fish" (Table 1), otoliths

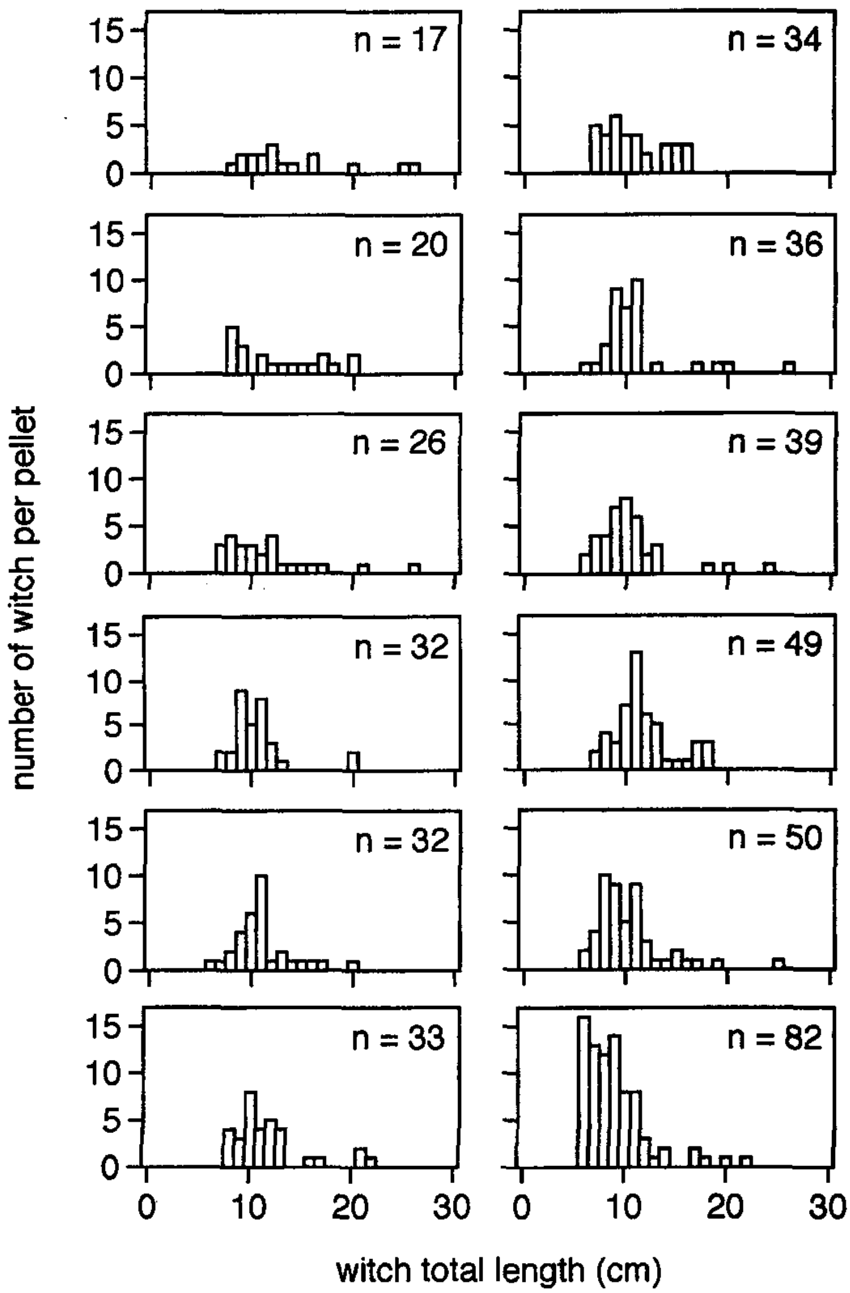

FIGURE 1 - Estimated frequency distributions for body lengths of witch in 12 pellets collected on 14 November 1991

from six of these fish resembled those of silver conger (*Gnathophis habenatus*: Congridae).

Crustaceans formed a negligible component of the diet (Table 1). They accounted for no more than 1% by number and by wet mass on both sampling dates. Relatively small fish and crustaceans, especially penny crabs (Hymenosomidae), might have been derived from the stomach contents of witch rather than having been taken directly by King Shags. The possibility of secondary origin of prey cannot be deduced from pellet analysis. However, their overall contribution was trivial in the shag diet.

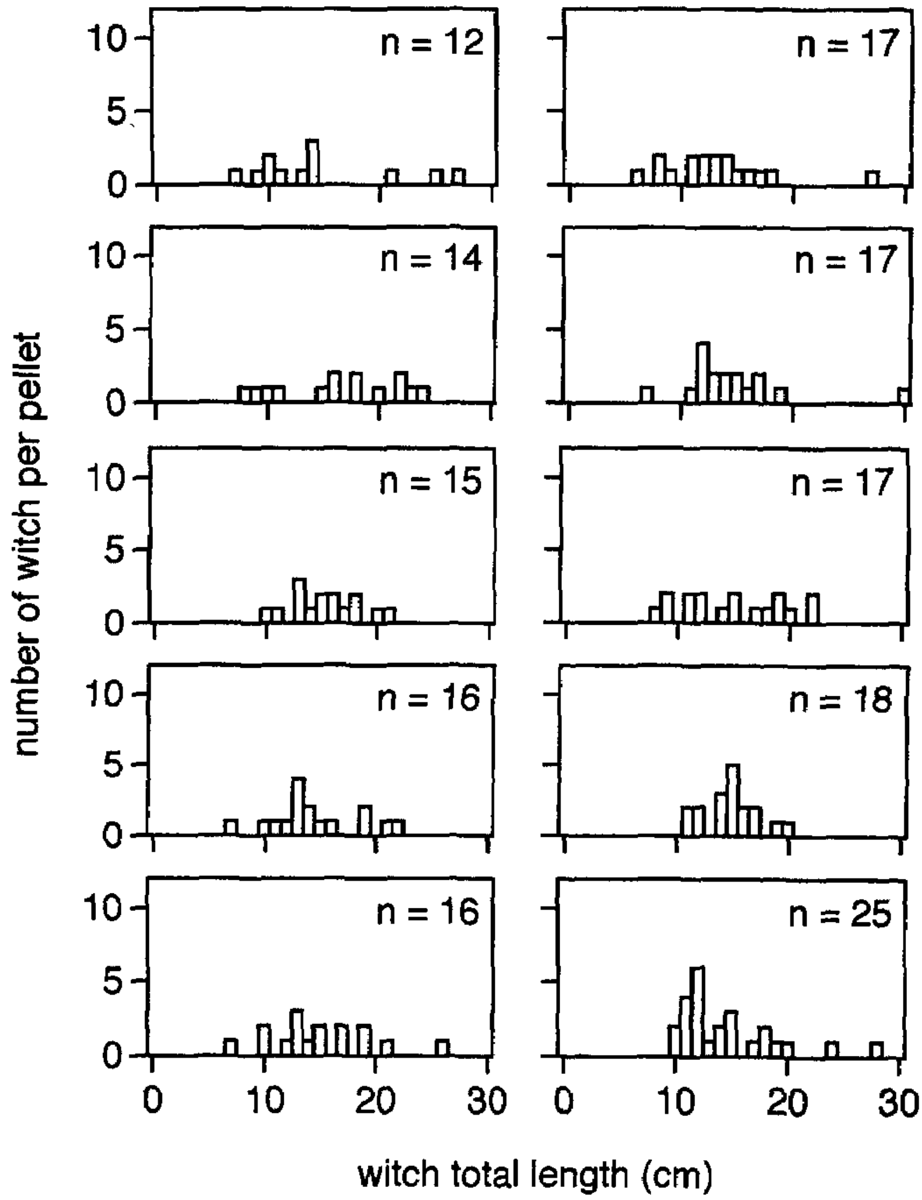

FIGURE 2 - Estimated frequency distributions for body lengths of witch in 10 pellets collected on 6 May 1992

Variability in prey represented in pellets

Witch predominated in every regurgitated pellet. For pellets collected on 14 November 1991, number of witch per pellet varied five-fold with a range 17-82 (Figure 1), mean 37.5 (*n* = 12, *s.d.* = 17.12). Concomitantly, the total number of prey items represented in each pellet ranged between 17 and 85, mean 41.4 (*n* = 10, *s.d.* = 18.22). For pellets from 6 May 1992, the range in number of witch per pellet was reduced to a two-fold range 12-25 (Figure 2), mean 16.7 (*n* = 10, *s.d.* = 3.40), and concomitant total number of prey items with range 14-25, mean 18.6 (*n* = 10, *s.d.* = 3.03). These differences in numbers of prey items represented in

TABLE 2 - Estimated wet mass of the dominant prey, witch per King Shag pellet on two collecting dates in the Marlborough Sounds

	13 November 1987	5 May 1988	All pellets
Range (g)	436 - 938	552 - 986	436 - 986
Mean (g)	656	697	674
s.d.	144	139	140
Number of pellets	12	10	22

pellets between the two sampling dates were significant. Pellets collected on 14 November 1991 contained more witch (t = 3.77, *d.f.* = 20, $p < 0.01$) and concomitantly overall more prey items (t = 3.90, *d.f.* = 20, $p < 0.01$) than pellets from 6 May 1992.

The extremes in diversity of prey represented in pellets from 14 November 1991 varied between one pellet that contained only remains of witch and two pellets that contained remains of six genera (mean = 3.25, n=12, *s.d.* = 1.54). Equivalent figures from 6 May 1992 were one pellet that contained only witch with the remainder containing two or three genera (mean = 2.40, n = 10, *s.d.* = 0.70). The difference in the mean number of prey genera per pellet between the two sampling dates was not statistically significant (t = 1.60, *d.f.* = 20, $p > 0.05$).

Seasonal change in size of witch

Modes in the estimated lengths of witch represented in each regurgitated pellet varied between 6 cm and 11 cm from the November sample (Figure 1) and between 12 cm and 15 cm from the May sample (Figure 2). These length-frequency distributions of witch taken by King Shags were summed for each sampling date (Figure 3). The modal lengths differed between the two sampling dates (November = 9-11cm and May = 12-16 cm) although ranges were similar (November = 6-26 cm and May = 6-29 cm). The estimated mean length of witch taken in May was 14.8 cm (n = 167, *s.d.* = 4.47), significantly longer than the mean length of 10.8 cm (n = 450, *s.d.* = 3.64) taken in November (t = 11.23, *d.f.* = 615, $p < 0.001$).

Wet mass of witch per pellet

Witch accounted for approximately 95% of the total wet mass of prey represented in pellets (Table 1). The wet mass of individual witch taken by King Shags showed similar two-fold ranges and relatively large standard deviations from both sample dates (Table 2). A t-test on normalised data (square root transformation) showed that the mean wet mass of individual witch represented in pellets was not significantly different between the two sample dates (Table 2: t = 0.67, *d.f.* = 20, $p > 0.05$). A search for a predictive relationship between size and number of prey items represented in pellets revealed an inverse relationship between mean wet mass of witch (y) and number of witch (x) per pellet (Figure 4: $y = 528x^{-0.94}$, $r^2 = 0.84$, n = 22, $p < 0.001$). The outcome of this predictor was that the total wet mass of witch per pellet was theoretically almost constant. This can be shown over the magnitude

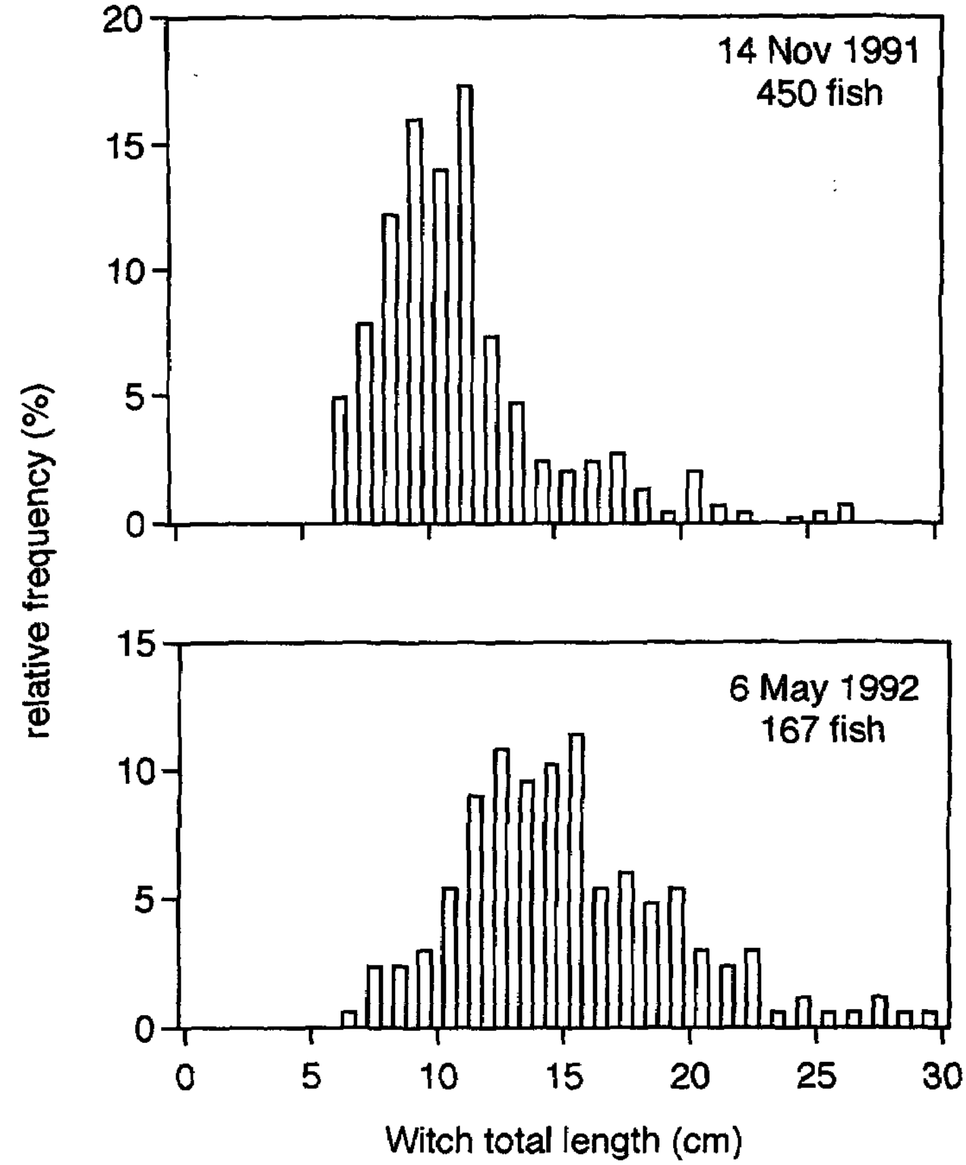

FIGURE 3 - Estimated frequency distributions for body lengths of witch from two samples of pellets collected six months apart

range in number of prey items recorded. At 10 witch per pellet, fish would average 60 g with a total wet mass of 600 g. At 100 witch per pellet, fish would average 6.8 g with a total wet masst of 684 g. Therefore, a ten-fold increase in number of prey items per pellet theoretically would produce only a 14% increase in total wet mass per pellet.

DISCUSSION

This diet study coincided with a comprehensive investigation of the breeding, distribution, abundance and foraging dispersion of New Zealand King Shags by Schuckard (1994). Typically less than five King Shags (range 0-22) roosted at Te Kaiangapipi, the source of regurgitated pellets for our study, and numbers there

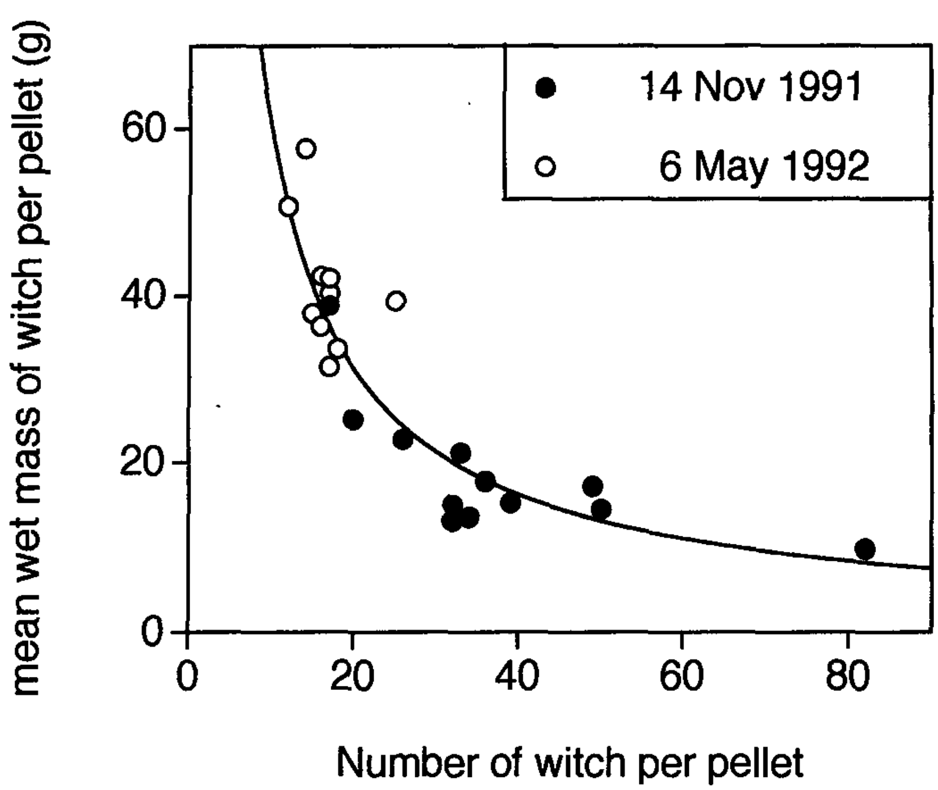

FIGURE 4 - Relationship between average size and total number of Witch per pellet collected from King Shags on 14 Nov 1991 and 6 May 1992

lacked distinct seasonal trends (Schuckard 1994). The only breeding location within Pelorus Sound was adjacent to the mouth of the sound at Duffers Reef (40° 57' S, 174° 02' E). In 1992, this colony accounted for 168 birds (32% of the species total) and 69 nests (42 % of the species total) and three-quarters of these birds foraged within Pelorus Sound (Schuckard 1994). Therefore, Pelorus Sound accounts for about 25% (0.32 x 0.75) of the foraging of all King Shags. Birds from Duffers Reef travelled an average distance of 8 km, maximum 24 km, to feed (Schuckard 1994). Duffers Reef is situated 10 km seaward of Te Kaiangapipi, and so we can assume that the regurgitated pellets collected at Te Kaiangapipi came from birds feeding in Pelorus Sound. Annual courtship and breeding by King Shags is spread across six months from March to August (Schuckard 1994). Therefore, our November 1991 sample coincided with the non-breeding period of King Shags and our May 1992 sample coincided with the breeding period. Remains of witch dominated all pellets. Not only was there little individual variation in the composition of the diet, but also the results were similar from two samples taken six months apart. We conclude that our results can be taken as representative of the annual diet of King Shags foraging in Pelorus Sound.

Our results support the deduction that King Shags prey primarily on bottom-dwelling fish (Nelson 1971, Marchant & Higgins 1990, Schuckard 1994). However, there was little overlap in species that we recorded as prey and those in published reports based on incidental observations: blue cod (*Parapercis colias*), red scorpionfish (*Scorpaena papillosus*), red rock lobster (*Jasus edwardsii*) and crabs by Falla (1932, 1933); pilchard (*Sardinops neopilchardus*), red cod (*Pseudophycis bachus*) and lobster krill (*Munida gregaria*) by Oliver (1955); and common sole (*Peltorhamphus novaezeelandiae*) and sandfish (*Gonorynchus gonorynchus*) by Nelson (1971). Witch, in particular, have not been recorded previously as prey of King Shags, although in our study they accounted for 90% of prey numbers and 95% of total estimated prey wet mass. This anomaly indicates that our study restricted to Pelorus Sound cannot be taken as representative of King Shags elsewhere in Marlborough Sounds.

Although witch grow to 40 cm long they are regarded as inedible to humans because they are thin-fleshed and bony, a sentiment reflected in their Maori name, mahue, meaning "to be left behind" (Graham 1956). The only species recorded from King Shags in Pelorus Sound that were of interest to commercial or recreational fisheries were righteyed flounders: lemon sole (*Pelotretis flavilatus*), flounder (*Rhombosolea* sp.) and sole (*Peltoramphus* sp.). However, their combination accounted for only 1-3 % of the King Shag diet.

Biological survey scuba dives were made by DB (unpubl. data) in the outer Pelorus Sound within the King Shag foraging range as identified by Schuckard (1994). These surveys indicated that shag prey species such as opalfish, blue cod, pilchard, flounder, sole and lobster krill are all sufficiently abundant to feature in greater numbers in the diet if prey species were randomly targeted within the foraging depths of King Shags. The absence or only trivial occurrence of these species in pellets further supports our inference that King Shags are actively targeting witch over other available prey items in this area.

Witch are the most abundant flatfish in New Zealand waters (Ayling & Cox 1982). Their range extends from shallow coastal waters out to the continental slope, and they are more common at greater depths than righteyed flounders (Graham 1956, Livingstone 1987). King Shags in Pelorus Sound typically forage in water 10-50 m deep, with none recorded in depths less than 10 m and 60% in depths greater than 30 m (Schuckard 1994). King Shags are perhaps targeting witch in depths beyond the range where righteyed flatfishes are numerous.

Witch have an annual spawning period that extends across eight months from August to April (Ayling & Cox 1982). This breadth complicates any attempt to validate age assessments from seasonal progression of modes in length-frequency analyses. Many species of fish can be aged from a count of opaque rings in their otoliths (Blacker 1974). A preliminary study of trawled fish by CL (unpubl. data) indicated that witch at one-year old were 12-19 cm *TL*. This technique has not been validated for witch and, therefore, must be interpreted with caution. However, results matched those available for fast-growing northern hemisphere Bothidae at one-year old: 20 cm for turbot (*Scopthalmus maximus*) and 13 cm for brill (*S. rhombus*) (Wheeler 1969). Regurgitated pellets from King Shags were collected on two dates six months apart. Each date exhibited only one obvious mode in the length-frequency for the estimated lengths of witch taken. Fish less than 20 cm long predominated on both dates, but their average estimated length increased by 4 cm between November 1991 and May 1992. Consequently, the same juvenile (first year) cohort of witch was probably represented on both dates. Although far from conclusive, results indicated that King Shags feeding in Pelorus Sound targeted juvenile witch throughout the year. A reliance on these juvenile fish would leave King Shags vulnerable to a potentially chronic food shortage following a poor spawning season by witch.

Calculations for a theoretical estimate of the daily food requirement for non-breeding shags have been formulated by Barrett *et al.* (1990):

$BMR = 433.5\ m^{0.734}$ (where m = bird body mass in kg)
assimilation efficiency = 85 %
energy content of small fish = 5.5 kJ g^{-1}

Daily energy expenditure (*DEE*) was estimated as 3 x basal metabolic rate (*BMR*). Published records for body mass of King Shags are limited to only two birds at 2.5 kg and 2.7 kg (Marchant & Higgins 1990). These body masses applied to the above relationships produce a theoretical *DEE* equivalent to a daily consumption of 545-575 g of fish. This range is 12-22 % lower than the average estimated total wet mass per pellet of 655 g in November 1991 and 695 g in May 1992. The accuracy of the calculation for *DEE* would be improved with a larger sample of body masses of healthy King Shags and a species-specific value for the energy content of witch. The similarity between values for total wet mass per pellet and theoretical *DEE* for King Shags indicates that complete regurgitated pellets may represent daily food intake. This is the case in at least some other species of shags (Lalas 1983, Barrett *et al.* 1990).

The classification and taxonomic relationships of shags are in a state of confusion (Marchant & Higgins 1990). Following the nomenclature of Turbott (1990), *Leucocarbo* is a circumpolar genus encompassing the "blue-eyed shags" (Devillers & Terschuren 1978) through temperate to polar southern latitudes. Sedentary populations of blue-eyed shags target bottom-dwelling prey whereas dispersive or migratory populations include a high proportion of pelagic prey (Punta *et al.* 1993). Consequently, the foraging habits of King Shags reflect those of other sedentary populations of blue-eyed shags. Recorded diving depths exceeding 50 m for King Shags in Pelorus Sound (Schuckard 1994) appear well within the capability of the species when compared with average diving depths up to 84 m (maximum 197 m) reported for similarly sized Imperial Shags (*L. atriceps*) at South Georgia (Kato *et al.* 1992).

Our results are applicable to about one-quarter of the total King Shag population. However, comparisons with earlier incidental records of prey species indicate that they cannot be extrapolated to King Shags elsewhere in their restricted distribution. Sampling at Te Kaiangapipi in November and May should be repeated to determine whether the diet of this group of King Shags remains constant or changes over time. Some idea of the prey of King Shags elsewhere in Marlborough Sounds could be obtained from the analysis of a contemporary collection of regurgitated pellets from as many colonies and roosts as possible. Disturbance of birds can be minimised by collecting during the non-breeding period. The number of pellets collected at each site needs to be large enough to be representative but, at an average of 5 h analysis per pellet, small enough to be practical. We suggest that about 10 fresh and complete pellets per site would be adequate if prey composition were similarly uniform to that reported in this manuscript but more would be required if the diet varied. Future dietary studies should aim to determine if the small population size and restricted distribution of King Shags are related to the availability of food.

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REVIEW

Birds as monitors of environmental change. By R.W. Furness & J.J.D. Greenwood (Editors) 1994. Chapman & Hall, London. ISBN 0-412-40230-0 (hardback) 356 pp.

Because no organism is able to live under all conditions, but only under a set of well defined, often narrowly limited conditions, the presence of any organism indicates those conditions. This indication concept has often been used, and occasionally misused by enthusiastic people bent to generate more interest, funding or simply recognition of their work, or beloved group of organisms. Thus came that 'indicator organisms' and 'monitoring' have become buzzwords with sometimes confusing meaning. Neither birds nor ornithologists are exempt of suffering from, and occasionally contributing to this suboptimal state of affairs. Yet birds can signal changes in environmental conditions, and striking examples of this range from the canaries miners kept to alert them to danger under ground to raptors who became the unwilling signallers of the overuse of pesticides.

Birds can also serve as monitors of environmental change. This book surveys this role of birds in 7 chapters. Two introductory chapters discuss the potential of birds to serve for this purpose, and the nature of environmental changes. More specific areas reviewed include pollution (ch.3), raionuclide contamination (ch. 4), (fresh)water quality (ch. 5) and the role of seabirs as indicators of marine prey stock levels (ch. 6). The final chapter deals with 'integrated' population monitoring.

This is a book with mainly British authors, several of whom works, or worked, for the British Trust for Ornithology. Some chapters show a European bias stems probably from this fact. In general, the references are in the 70-ies and 80-ies, a bit dated for a book that was originally published in 1993. Unevenness in the detail and value of the individual chapters is nearly inevitable as authros of individual chapters are often opportunistically recruited. The chapter on radionuclides, for example, shows a baffling superficiality in dealing with the bird studies on the effects of the Chernobyl disaster that are extensive and very interesting. The integrated population monitoring chapter, in my view, fails to enlighten the reader about the concept. I was left with the impression that anything can be monitored, and that, occasionally, any of these is worth monitoring. This is a discouraging message and provides little guidance when planning monitoring studies.

Gábor Lövei