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Feasibility of ageing shovelnose dogfish (*Deania calcea*), leafscale gulper shark (*Centrophorus squamosus*), and seal shark (*Dalatias licha*)

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Final Research Report

Report Title:	Feasibility of ageing shovelnose dogfish (*Deania calcea*), leafscale gulper shark (*Centrophorus squamosus*), and seal shark (*Dalatias licha*)
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7. Executive Summary

Length-frequency data, eye lenses, vertebrae and dorsal fin spines of shovelnose dogfish, leafscale gulper shark, and seal shark were examined in an attempt to develop suitable ageing techniques for these species. Lenses were measured and weighed, and frequency distributions of these variables were examined for modal structure that might correspond with age classes. Vertebrae and spines were sectioned and examined under a variety of lighting and after X-raying and staining to visualise growth bands.

Length-frequency data for all three deepwater shark species suffered from a number of problems that ruled out any rigorous analysis of modal structure, and therefore determination of age compositions and growth rates. Some of the problems resulted from small sample sizes and the unavailability of representative samples of the population. These problems could be overcome, with some difficulty, by more comprehensive sampling over larger regions of the Exclusive Economic Zone. More problematic, for shovelnose dogfish at least, is the lack of modal progression of the 0+ mode during the year, probably as a result of the lack of a distinct pupping season. It is therefore unlikely that clear modes representing distinct age classes would be visible in samples even if they were representative of the whole population. It appears that, for shovelnose dogfish at least, length-frequency analysis is unlikely to be useful for estimating growth rate and age composition.

Frequency distributions of eye lens diameters and weights of the three species showed some promise for identifying age classes, but their utility could not be determined in this study because of small sample sizes.

Vertebrae of all three shark species were poorly calcified and lacked distinct banding patterns. For the few vertebrae with visible bands, band counts were always lower than on the dorsal fin spines of the same specimens; we judged the latter more likely to be correct, and concluded that vertebral counts are unreliable as age estimates.

Fin spines sectioned transversely and viewed with transmitted white light produced the most promising results for shovelnose dogfish and leafscale gulper shark (seal shark lacks fin spines). The spine sections had more-or-less distinct concentric bands that are presumably deposited annually; the same banding structure has been used to age these two species in the northeastern Atlantic.

For shovelnose dogfish, two readers had moderately good agreement overall in band counts, albeit with considerable variability for individual sharks. Considering that neither reader had had previous experience ageing these sharks, and that the two readers did not compare results or attempt to develop an agreed ageing protocol, we believe that ageing shovelnose dogfish from dorsal fin spines is highly feasible. The maximum age reported for Atlantic shovelnose dogfish is 35 years compared with our greatest band count of 20; however the largest shark in our sample was only 85 cm total length, compared with a maximum length for this species exceeding 120 cm.

For leafscale gulper shark, two readers produced substantially different spine band counts. This may reflect the difficulty of reading these sections, and inexperience with this species. Reader 1's counts, which gave a maximum of 27 bands for a 136 cm total length shark, were more consistent with those of leafscale gulper sharks from the northeastern Atlantic, where most sharks of 100–120 cm were estimated to be 20–40 years old (with a maximum age of 70 years).

We conclude that band counts on sections of dorsal fin spines offer a feasible method for ageing shovelnose dogfish and leafscale gulper shark. Taken in conjunction with studies from the Atlantic Ocean, our spine band counts indicate that shovelnose dogfish and leafscale gulper shark are slow growing and long-lived. We are unable to provide any estimates of the growth rate and longevity of seal shark.

8. Objectives

2. To undertake a feasibility study, including initial small sample size trials of preferred methods, to determine the age of the shovelnose dogfish *Deania calcea*, the leafscale gulper shark *Centrophorus squamosus*, and the seal shark *Dalatias licha*.

9. Introduction

Deepwater shark species are often caught as bycatch in New Zealand commercial fisheries, particularly those for hoki and orange roughy. Shovelnose dogfish (*Deania calcea*), leafscale gulper shark (*Centrophorus squamosus*), and seal shark (*Dalatias licha*) are all frequently caught (Blackwell & Stevenson 2003; Livingston et al. 2003).

Concern has been raised about the ability of deepwater sharks to sustain anything other than low levels of fishing mortality. Their productivity is thought to be low as a result of low growth rates and fecundity. Shallow water spiny dogfishes have been aged using growth bands on their second dorsal fin spines (Holden & Meadows 1962; Ketchen 1975; Soldat 1982; Cannizzaro et al. 1995), but until recently few deepwater sharks had been aged. This reflects the small size and low value of their fisheries, and the difficulty of ageing cartilaginous species. Tanaka (1990) found that decalcification of longitudinal spine sections followed by staining with Meyer's haematoxylin produced countable growth bands in Japanese *Centrophorus acus*. Clarke et al. (2002a) examined the vertebrae and second dorsal fin spines in *Centrophorus squamosus* from the northeastern Atlantic Ocean. Vertebrae revealed no banding after sectioning and staining, but sections of the inner dentine layer of the second dorsal fin spine had bands which the authors assumed to be annual. Machado & Figueiredo (2000) tried a variety of ageing techniques on the second dorsal spine of Portuguese *Deania calcea*, including thin and thick sectioning, acetone clearing, decalcification, heating and several stains, and found that a technique similar to Tanaka's was best for ageing. Clarke et al. (2002b) also successfully aged *D. calcea* from Ireland using thick sections of dorsal fin spines.

Other shark ageing techniques have not yet been tried on deepwater sharks; these include X-radiography of vertebral sections and spine sections, viewing thick spine sections with polarised light and ultraviolet light, and eye lens ageing. Seal sharks do not have dorsal fin spines, so vertebrae and eye lenses offer the best chances of finding a useful ageing technique. However, deepwater sharks tend to have poorly calcified vertebrae, and so vertebral ageing may be unsuccessful.

Eye lenses are suspended in fluid, and their growth may be uncoupled from growth of the rest of the body (in the same way that otolith growth is uncoupled from somatic growth in teleosts). This means that eye lenses may continue growing after body growth has slowed or stopped. Studies on several fishes have found that eye lens weight-frequency distributions or diameter-frequency distributions may exhibit clear, separable modes for several years. They may therefore provide a useful ageing technique for juvenile and possibly adult sharks. Eye lens weights have been used to identify juvenile age classes of spiny dogfish (Siezen 1989). Eye lens diameters have considerable promise for ageing New Zealand dark ghost sharks, but were less successful for pale ghost sharks (Francis & Ó Maolagáin 2001, 2004).

Validation and verification of fish ageing techniques is an important requirement in age and growth studies (Beamish & McFarlane 1983). Unfortunately, validation for deepwater sharks is beyond the scope of the present proposal. However, ageing verification may be possible by comparing age-based growth estimates with length-based estimates derived from length-frequency distributions.

In this report, we present a preliminary study of length-frequency distributions, eye lens diameters and weights, vertebrae, and fin spines of shovelnose dogfish, leafscale gulper shark, and seal shark in an attempt to develop ageing techniques for these three species.

10. Methods

Shark samples

Deepwater sharks were collected from the Chatham Rise and the Subantarctic during research trawl surveys (Table 1). Most samples came from the Chatham Rise. Further specimens were requested from the Ministry of Fisheries observer programme, but none were received.

Table 1: Date and place of collection for deepwater shark specimens used in this study. Bold numbers indicate samples used for eye lens analyses.

Species	Voyage	Region	Period	Females	Males	Total
Shovelnose dogfish	TAN0208	Chatham Rise	Jun–Jul 2002	**32**	**100**	132
	TAN0213	Chatham Rise	Sep–Oct 2002	3	1	4
	TAN0301	Chatham Rise	Dec 2002 – Jan 2003	27	13	40
	Total			62	114	176
Leafscale gulper shark	TAN0208	Chatham Rise	Jun–Jul 2002	**40**	13	53
	TAN0219	Subantarctic	Nov–Dec 2002	3	4	7
	TAN0301	Chatham Rise	Dec 2002 – Jan 2003	6	7	13
	Total			49	24	73
Seal shark	TAN0208	Chatham Rise	Jun–Jul 2002	2	0	2
	TAN0219	Subantarctic	Nov–Dec 2002	9	11	20
	TAN0301	Chatham Rise	Dec 2002 – Jan 2003	**13**	**25**	38
	TAN0401	Chatham Rise	Dec 2003 – Jan 2004	**29**	**25**	54
	Total			53	61	114

Sharks were sexed and measured fresh to the centimetre below total length (TL). They were then frozen and returned to the laboratory.

Length-frequency distributions

Length measurements made during research trawl surveys were aggregated into frequency distributions by sex, region and survey. Sample sizes of leafscale gulper shark and seal shark were low, but good numbers of shovelnose dogfish have been measured, particularly on *Tangaroa* Chatham Rise surveys and *Wanaka* North Island surveys. Length-frequency distributions were examined for the presence of modal structure that would enable identification of age classes using MULTIFAN software (Fournier et al. 1990).

Eye lenses

The analysis of eye lenses was restricted to data collected from the same region at the same time of year, to avoid potential confounding of results by regional differences and seasonal growth. Sample sizes were mostly small when broken down by sex (Table 1).

The left and right eye lenses were removed, sealed in zip-lock plastic bags, and frozen. The lenses consist of a solid crystalline core surrounded by a sticky gelatinous fluid, and encapsulated in a tough membrane. After thawing, lens cores were dissected out and the greatest core diameter was measured to the nearest 0.001 mm with a digital micrometer. The core was also weighed wet to the nearest 0.0001 g. Diameters were grouped into 0.2 mm class intervals, and weights were grouped into 0.02–0.05 g intervals for analysis. Differences between left and right lenses were tested using paired *t*-tests. Only data for the left lenses are presented here.

Vertebrae

Vertebral samples were collected from below the first dorsal fin. This region has the largest vertebrae, so band resolution was expected to be greatest there. Vertebrae were bleached briefly in sodium hypochlorite to remove any muscle and connective tissue. Whole vertebrae were examined under reflected light using a variety of incident angles. Subsamples were stained using chemicals that are known to delineate growth bands in other skate and shark species: silver nitrate, crystal violet, alizarin red, Meyer's haematoxylin, and cobalt nitrate/ammonium sulphide. Sections about 0.6 mm thick were cut from another subsample of vertebrae and examined under transmitted white light, differential interference contrast, ultraviolet light, and X-rays. Half centra were also X-rayed.

Fin spines

Growth bands formed in the external enamel layer of fin spines have been used to age shallow water squaloid sharks, notably *Squalus acanthias* (Holden & Meadows 1962; Ketchen 1975; Soldat 1982). However, in deepwater squaloid sharks, this enamel layer is not complete: it is usually reduced to three longitudinal ribs, and does not extend down the whole spine. Because of this, and the poor definition of enamel bands, the external enamel layer has not been used to age deepwater sharks (Clarke et al. 2002a, b). However, transverse sections taken through the spine reveal growth bands in the dentine layers. Spines grow by deposition of new cones of dentine inside the older cones (Holden & Meadows 1962; Soldat 1982). Bands in the inner trunk layer of dentine originate at the trunk primordium (see Figures 14, 15) by deposition of material along the lumen surface by odontoblasts (Clarke et al. 2002a; 2002b). New material is also added to the external surface by odontoblasts covering the portion of the spine embedded under the skin, but this material is not present in the exposed portion of the spine (Clarke et al. 2002b). Thus the full growth history is only apparent in the inner trunk layer. Sections taken too close to the spine tip do not contain the most recently deposited cones, and sections taken too close to the base do not contain the earliest cones. The best sectioning location is near where the lumen of the spine becomes constricted and occluded (Tanaka 1990; Clarke et al. 2002a, b). However, this location moves down the spine as the shark ages (through deposition of new dentine along the lumenal surface) (Holden & Meadows 1962).

In this study, we used transverse sections of the second dorsal fin spine to age subsamples of shovelnose dogfish and leafscale gulper shark. Seal sharks do not have dorsal fin spines. For most sharks, we took multiple sections at different distances from the tip and used the section(s) with the smallest lumen for ageing; however, in some sharks, particularly those with worn spine tips, none of the sections had a small lumen. Thus we cannot be sure that all growth bands were present in all sections. An alternative approach is to use longitudinal sections (Tanaka 1990), but as these make it impossible to cut transverse sections from the same spines, and because band definition is better in transverse sections, we used only the latter in this study.

In preparation for sectioning, spines were cleaned in hot water, air dried for about one week, and embedded in a block of epoxy resin (Araldite K142). Thick sections were cut with a dual-bladed, precision diamond saw (Struers Accutom 2). One side of each section was polished using a graduated series of carborundum paper, then glued to a glass microscope slide using thermoplastic cement. The other side of the section was similarly polished until rings became discernible under the microscope. Final section thickness ranged from 0.15 to 0.30 mm. Some sections were stained as described for vertebrae in an attempt to improve the clarity of the bands.

Growth bands in the spine sections were counted by two readers at 40–100x magnification using transmitted light. Band counts began at the trunk primordium (Clarke et al. 2002a, b) and proceeded towards the lumen. The outermost band of the inner trunk layer was omitted from the counts because it was assumed to be laid down before or near birth.

11. Results

Length-frequency distributions

Shovelnose dogfish

Length-frequency datasets for shovelnose dogfish caught during trawl surveys are listed in Appendix 1, and length-frequency distributions from the Chatham Rise are shown in Figure 1. Male distributions were dominated by a large mode of adults at 80–90 cm TL. In most years, there was also a long tail of juveniles at 30–70 cm, but numbers were low, and there was no obvious modal structure. Females exhibited a much more even length distribution between 30 and 110 cm, but again there was little apparent modal structure.

Wanaka surveys were carried out around North Island in four seasons of 1985–86 (Clark & King 1989). Stations from the west coast of North Island produced small numbers of juveniles less than 60 cm TL, and were dominated by adult males with a single mode at 80–90 cm (Clark & King 1989, figure 19). Stations from the east coast of North Island had a clear 0+ mode at 30–35 cm for both sexes (Figure 2). However this mode showed no progression during the four seasons sampled. The east coast samples also contained strong modes of adult males (80–90 cm) and adult females (100–110 cm). Between the 0+ and adult modes, there was a broad mode of sharks around 40–70 cm, followed by a 'gap' with few sharks at 70–80 cm for males and 70–100 cm for females (Figure 2). According to age estimates and growth curves from the northeastern Atlantic, the length range 40–70 cm should encompass ages 3–15 years (Clarke et al. 2002b). The 'gaps' present for both sexes should also cover many age classes.

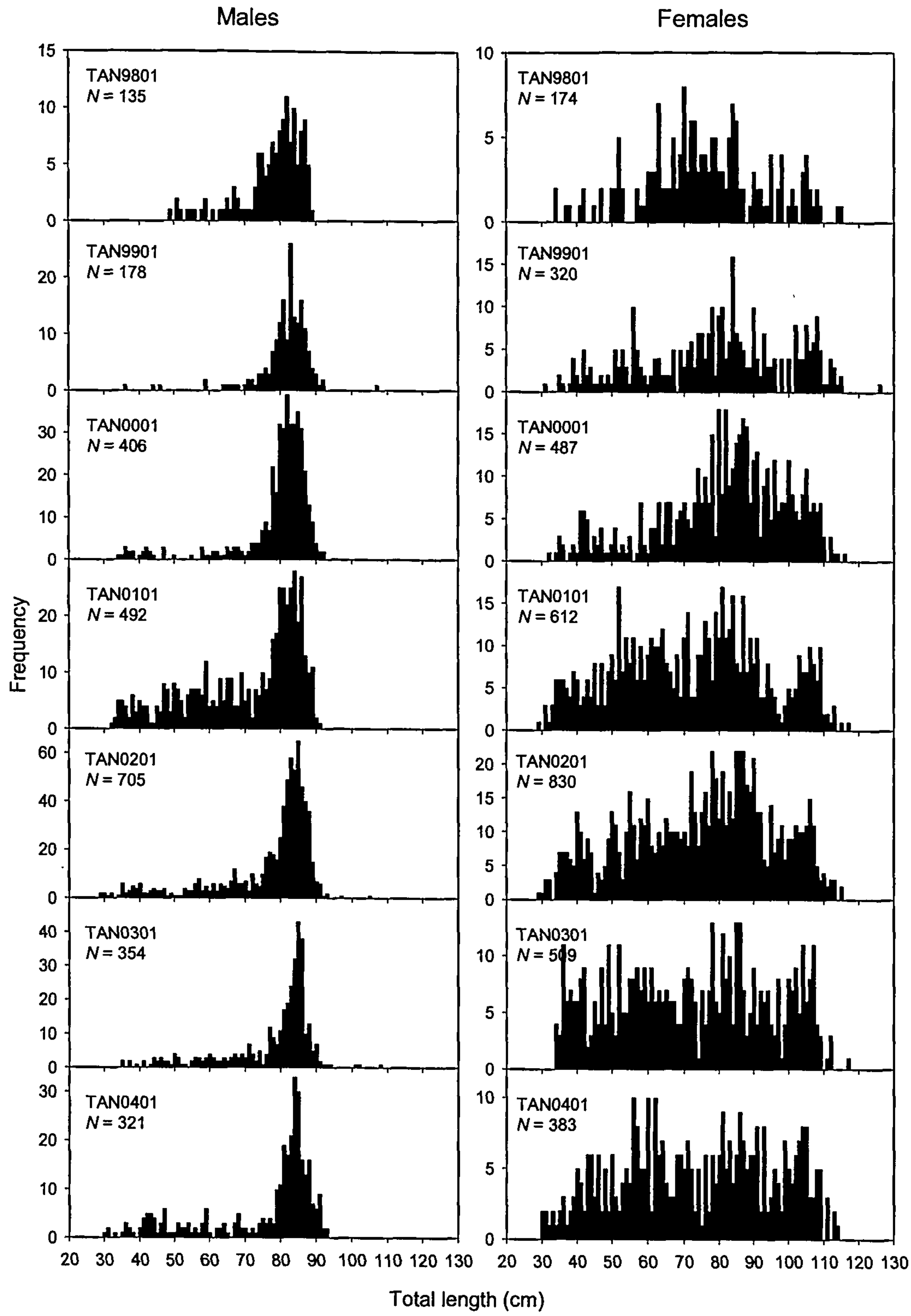


Figure 1: Length-frequency distributions of shovelnose dogfish sampled from Chatham Rise summer trawl surveys, 1998–2004.

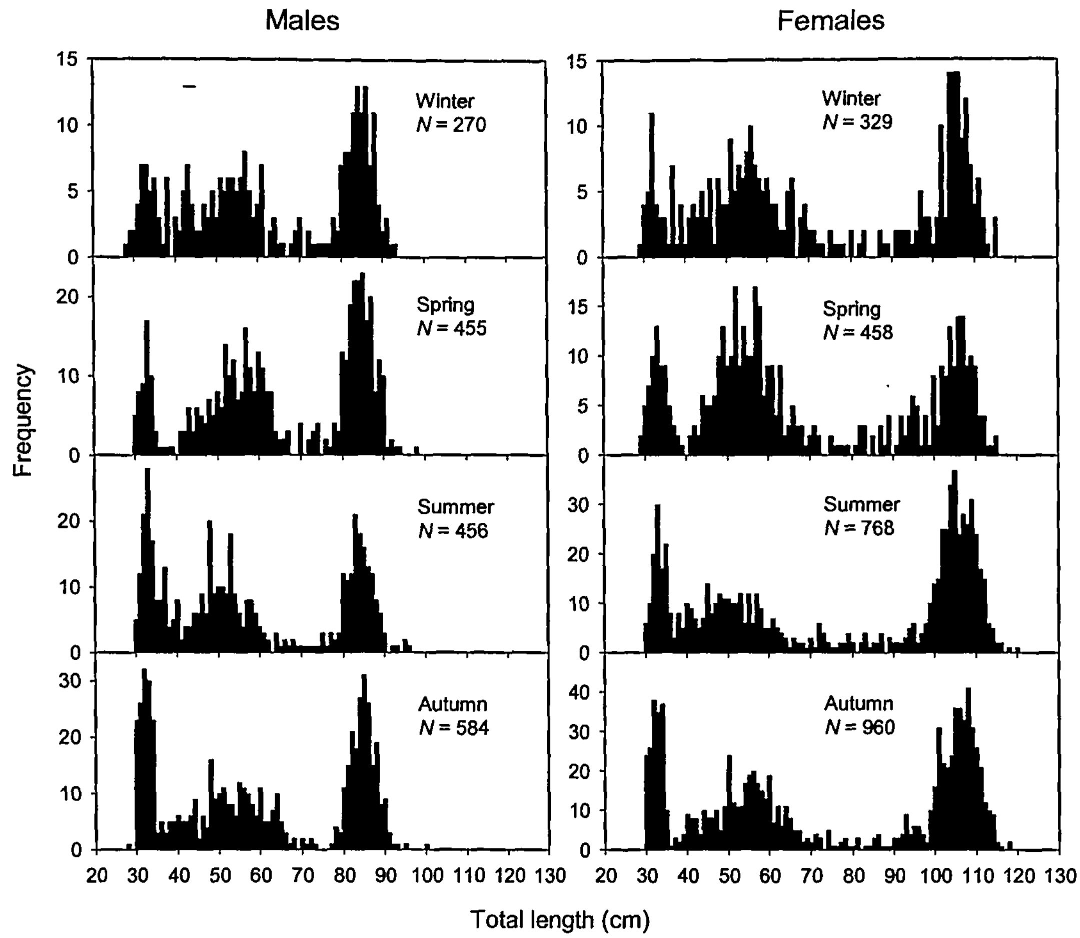


Figure 2: Length-frequency distributions of shovelnose dogfish sampled from eastern North Island trawl surveys in four seasons: winter 1985 (WNK8501), spring 1985 (WNK8502), summer 1985–86 (WNK8503), and autumn 1986 (WNK8604).

Thus the length-frequency data sets suffered variously from lack of juveniles, lack of adequate modal structure, missing age classes, and lack of modal progression of the 0+ age class. The last feature is consistent with observations that shovelnose dogfish do not have a strongly defined breeding season (Clark & King 1989). Other datasets did not provide better distributions. Therefore no MULTIFAN models were applied to the length-frequency data, because they were clearly uninformative for such analyses.

Leafscale gulper shark

Length-frequency datasets for leafscale gulper shark from trawl surveys are listed in Appendix 2. Only three datasets had measurements for more than 40 sharks, and their length-frequency distributions are shown in Figures 3–5. Sample sizes and modal structure were inadequate for further analysis.

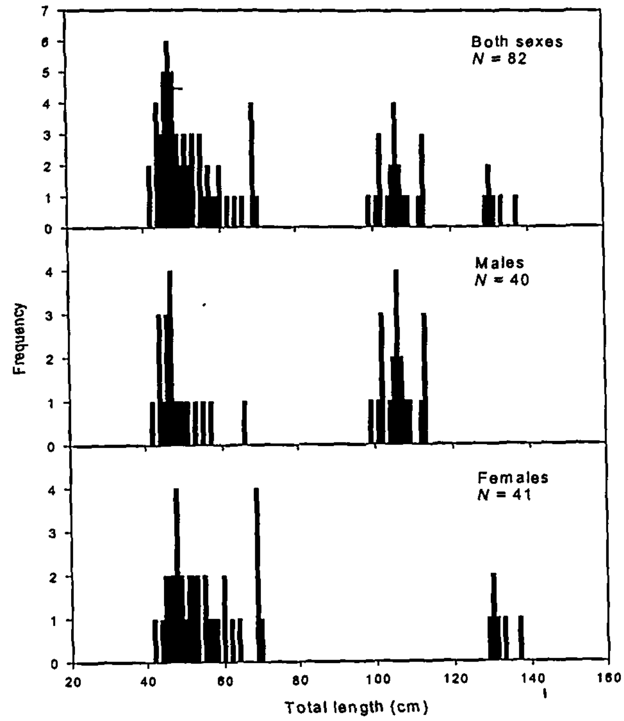


Figure 3: Length-frequency distributions of leafscale gulper shark sampled from a Subantarctic trawl survey in 2002 (TAN0219).

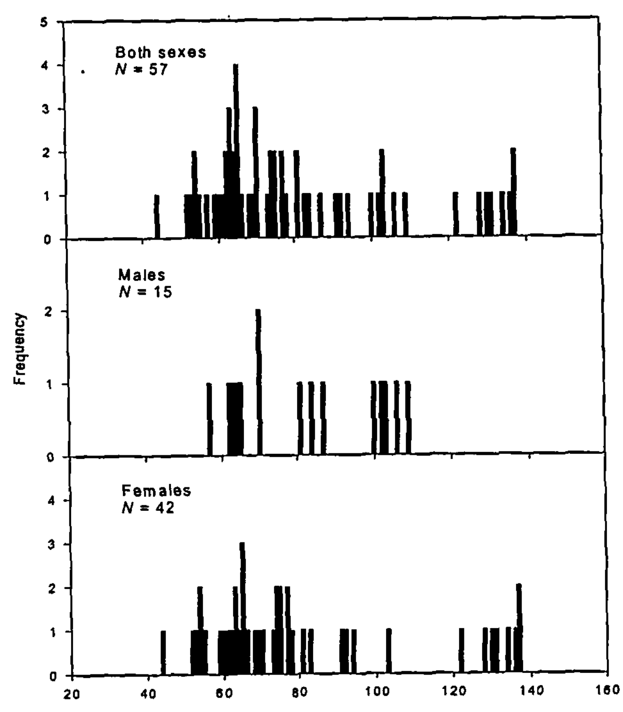


Figure 4: Length-frequency distributions of leafscale gulper shark sampled from a Chatham Rise trawl survey in 2002 (TAN0208).

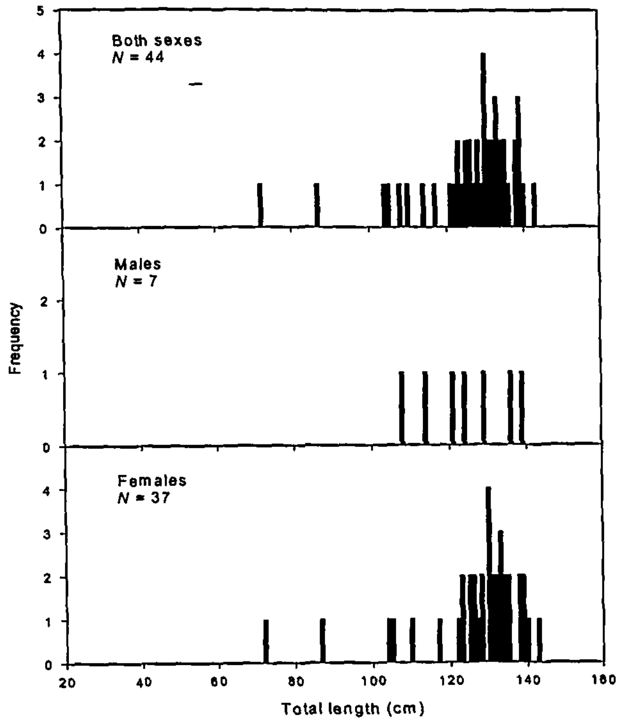


Figure 5: Length-frequency distributions of leafscale gulper shark sampled from a west coast South Island trawl survey in 2000 (TAN0007).

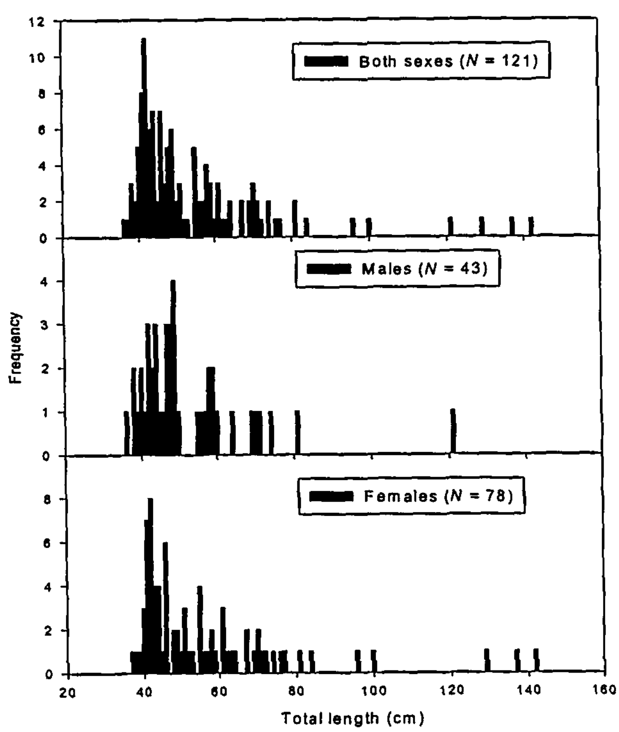


Figure 6: Length-frequency distributions of seal shark sampled from two Chatham Rise trawl surveys in 2003 and 2004 (TAN0301 and TAN0401).

Seal shark

Length-frequency datasets for seal shark from trawl surveys are listed in Appendix 3. Only two datasets had measurements for more than 40 sharks, and because they were sampled from the Chatham Rise at the same time of year, the datasets were pooled (Figure 6). Most sharks were juveniles with some indication of modal structure in the 35–60 cm length range, but this was considered inadequate for MULTIFAN analysis.

Eye lenses

For all three species, the left eye lens was, on average, slightly heavier and larger than the right lens. Paired *t*-tests showed that this difference was significant for the weight of shovelnose dogfish lenses (mean difference = 0.012 g, t = 3.37, N = 169, P = 0.0009) and the diameter of leafscale gulper shark lenses (mean difference = 0.070 mm, t = 2.33, N = 73, P = 0.0225). However the differences between left and right lenses were small and probably not biologically significant. It is not known whether these differences are real, or artefacts of measurement technique. To avoid confounding of results, we subsequently report only the diameters and weights of the left lenses.

Shovelnose dogfish

Sample sizes of both sexes, especially females, were too low to define adequately the modal pattern of lens diameters and weights (Figures 7 and 8). Furthermore the male sample had few juveniles. Nevertheless, adult males showed considerable modal structure in lens diameter and weight (Figure 7). This provides support for testing this technique on larger samples, though if New Zealand shovelnose dogfish have similar growth characteristics to those from the northeast Atlantic, we would expect the adult male length mode to comprise many age classes.

Leafscale gulper shark

Only the female sample was large enough to warrant examination, but it was too small to define age classes from lens diameters and weights (Figure 9).

Seal shark

Both males and females showed two clear lens weight modes that corresponded approximately with juveniles of 35–50 cm and 55–70 cm TL (Figures 10 and 11). However it is not known if these modes represent age classes. Clear modes were not present in lens diameters.

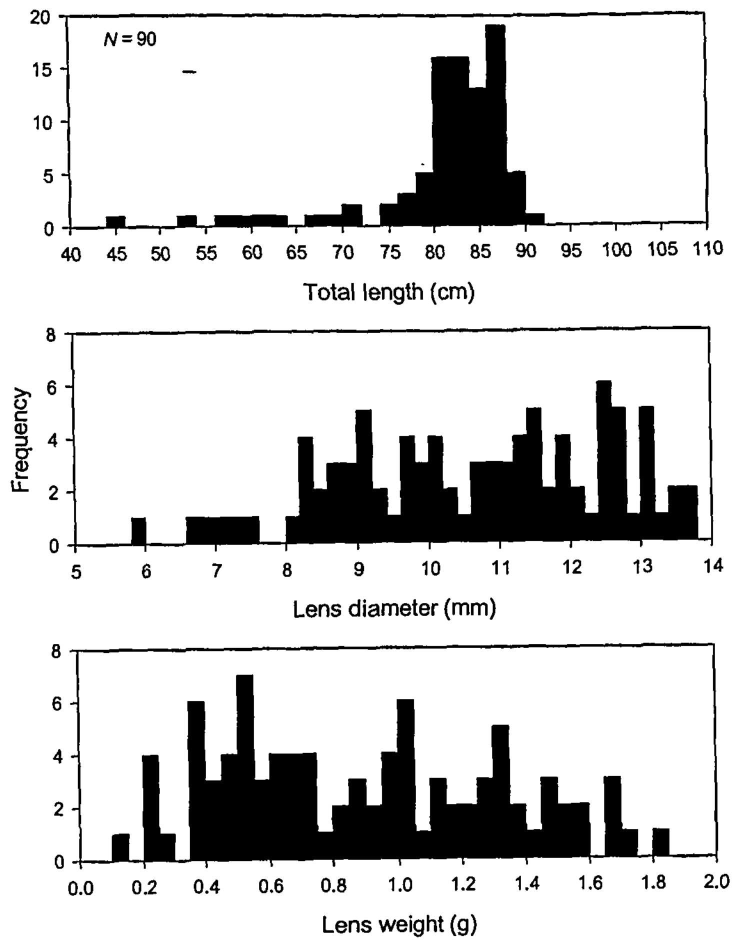


Figure 7: Length-frequency distribution, and eye lens diameter and weight distributions, for male shovelnose dogfish collected from the Chatham Rise in June–July 2002.

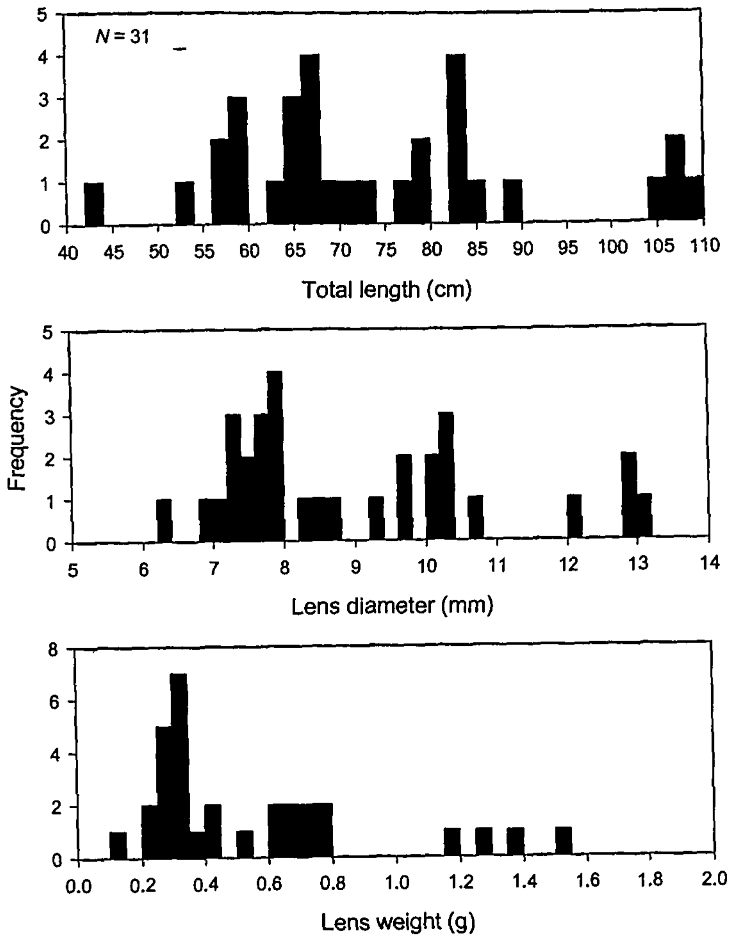


Figure 8: Length-frequency distribution, and eye lens diameter and weight distributions, for female shovelnose dogfish collected from the Chatham Rise in June–July 2002.

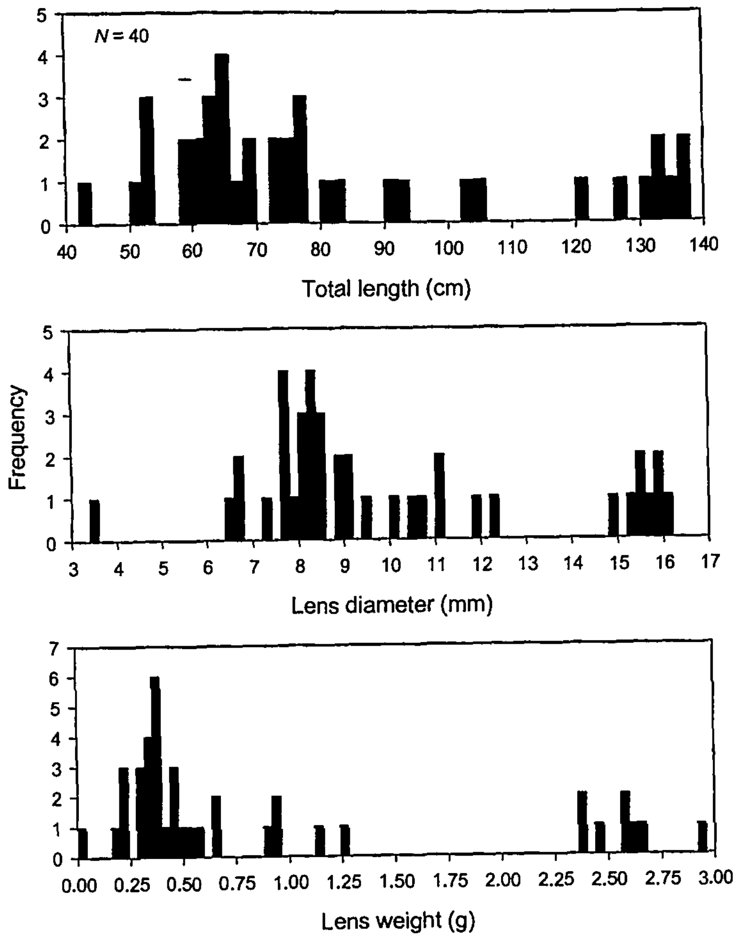


Figure 9: Length-frequency distribution, and eye lens diameter and weight distributions, for female leafscale gulper shark collected from the Chatham Rise in June–July 2002.

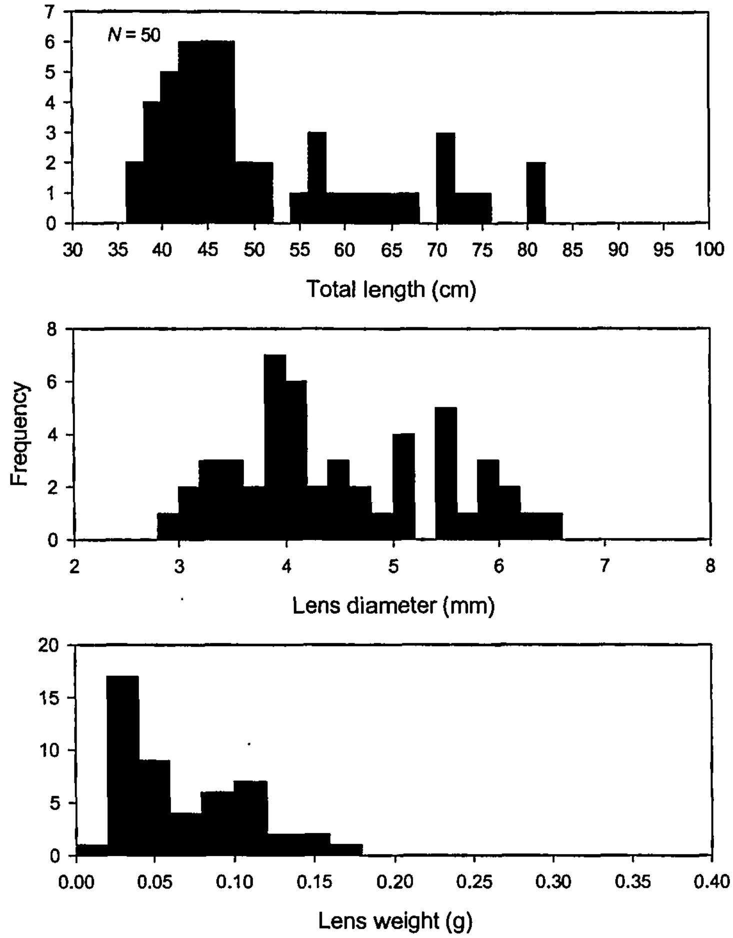


Figure 10: Length-frequency distribution, and eye lens diameter and weight distributions, for male seal shark collected from the Chatham Rise in December 2002–January 2003, and December 2003–January 2004.

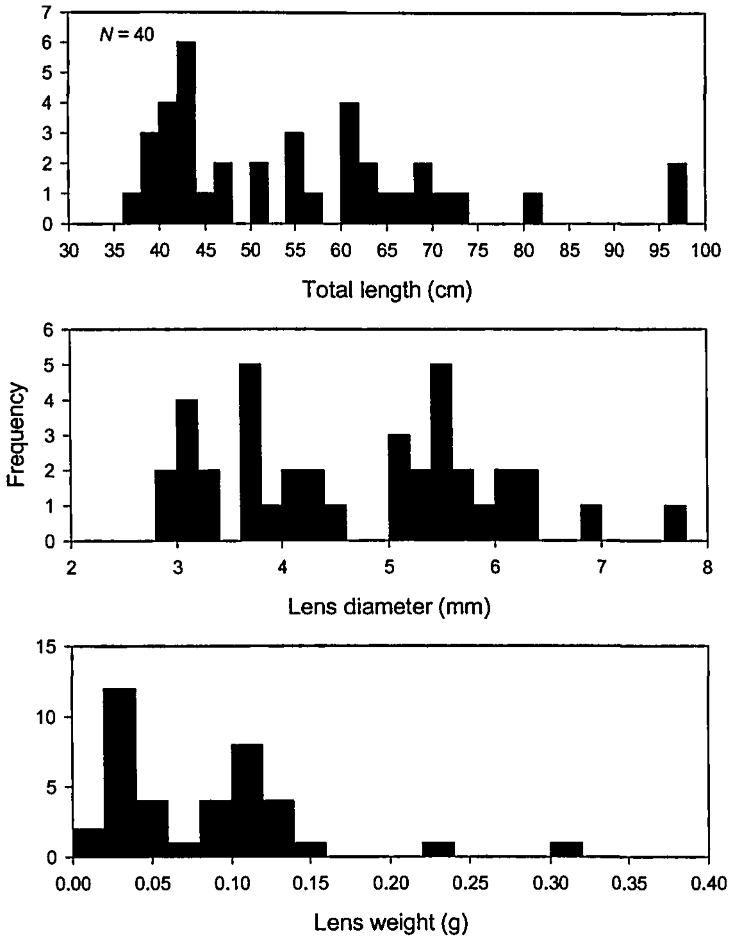


Figure 11: Length-frequency distribution, and eye lens diameter and weight distributions, for female seal shark collected from the Chatham Rise in December 2002–January 2003, and December 2003–January 2004.

Vertebrae

Vertebrae from all three species were poorly calcified. Some bands became visible on whole vertebrae of smaller sharks after shining light obliquely through them, but many vertebrae, especially for shovelnose dogfish and leafscale gulper shark, were unreadable (Figure 12). Staining did not help, because of the low calcification of the vertebrae. Thick sections of vertebrae viewed under a variety of light regimes, and X rays, showed little or no banding (Figure 13). While it was possible to obtain band counts from some vertebrae, the confidence in the counts was low, and the counts were always lower than counts made on spines from the same sharks. We believe that band counts from vertebrae are unreliable in these species.

Fin spines

Thick sections from dorsal fin spines of shovelnose dogfish and leafscale gulper shark contained concentric bands when viewed with transmitted white light (Figures 14 and 15). Differential interference contrast and reflected ultraviolet light did not significantly enhance the band clarity or readability.

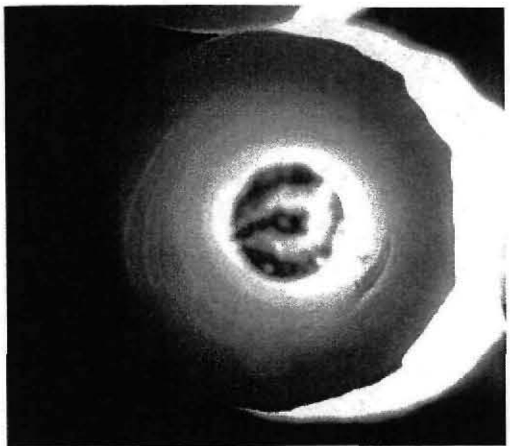
Growth bands were more clearly defined and more easily counted in shovelnose dogfish than in leafscale gulper shark. Sections taken near the tip of the spine were difficult to read because of a high density of canaliculi traversing the space between the lumen and the trunk primordium.

Shovelnose dogfish

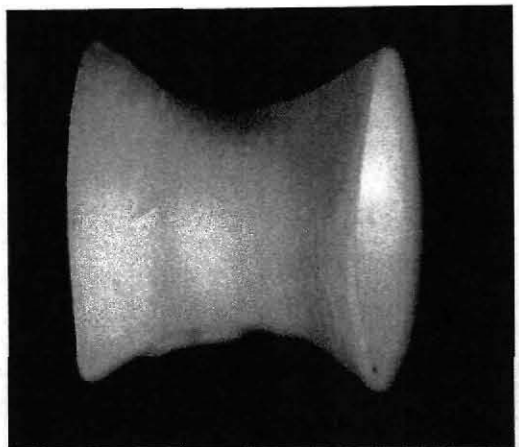
Band counts made by the two readers on a sample of spines were similar overall (there was no systematic bias) but the counts for individual sharks were quite variable (Figure 16). There was a plausible increasing relationship between total length and band count with no obvious difference between males and females (Figure 17).

Leafscale gulper shark

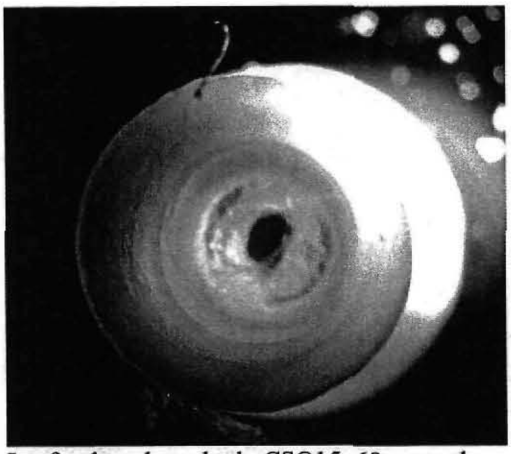
There was a clear difference in the band counts made by the two readers, with Reader 1 usually counting substantially more bands than Reader 2 (Figure 18). Reader 1's counts were considered more plausible (see Discussion), and were approximately linearly related to total length, with an indication of greater length-at-age for females than males among the older sharks (Figure 19).



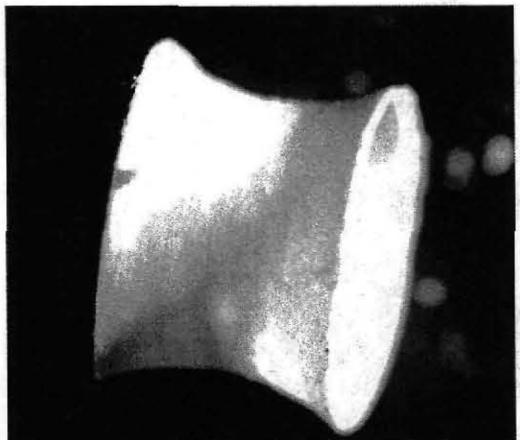
Shovelnose dogfish, SND132, 78 cm male



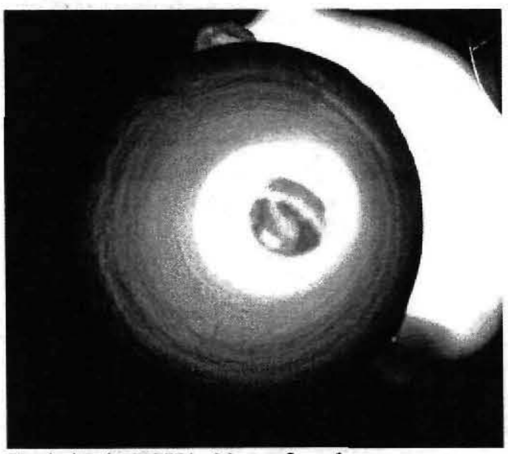
Shovelnose dogfish, SND154, 47 cm female



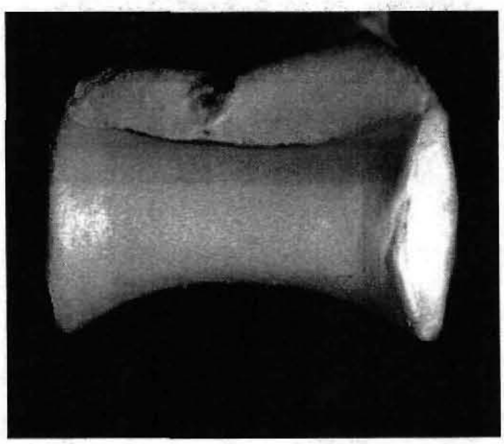
Leafscale gulper shark, CSQ15, 68 cm male



Leafscale gulper shark, CSQ7, 47 cm male



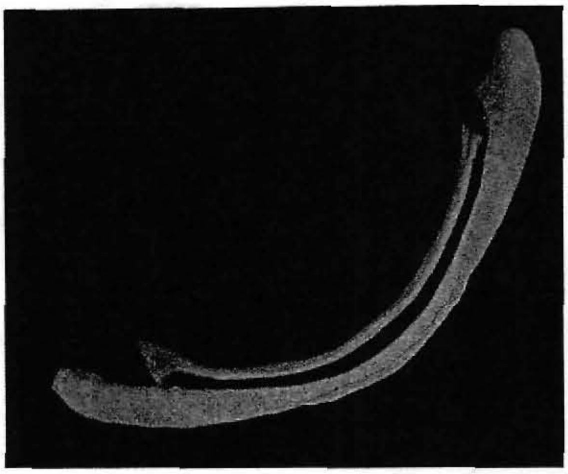
Seal shark, BSH1, 99 cm female



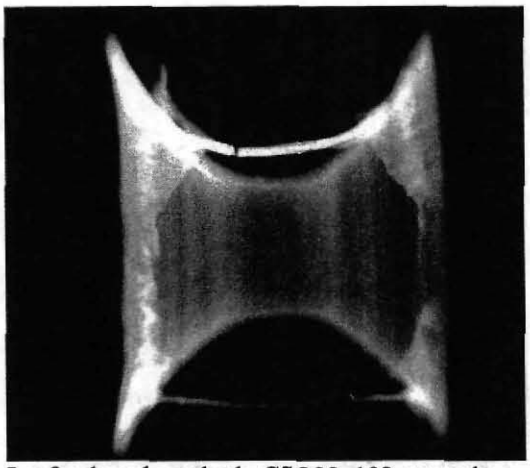
Seal shark, BSH17, 63 cm female

Figure 12: Whole vertebrae from three deepwater shark species illuminated obliquely with white light. Left images show vertebral centra from the anterior or posterior end; right images show centra from the side.

Shovelnose dogfish, SND132, 78 cm male

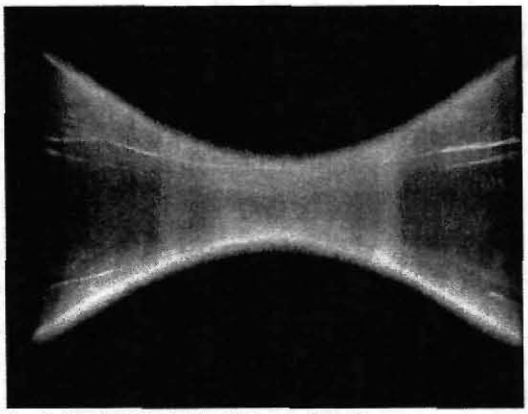


Shovelnose dogfish, SND134, 80 cm male



Leafscale gulper shark, CSQ22, 102 cm male

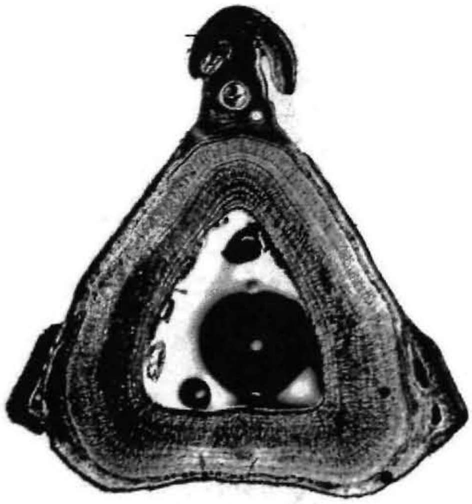
Leafscale gulper shark, CSQ22, 102 cm male



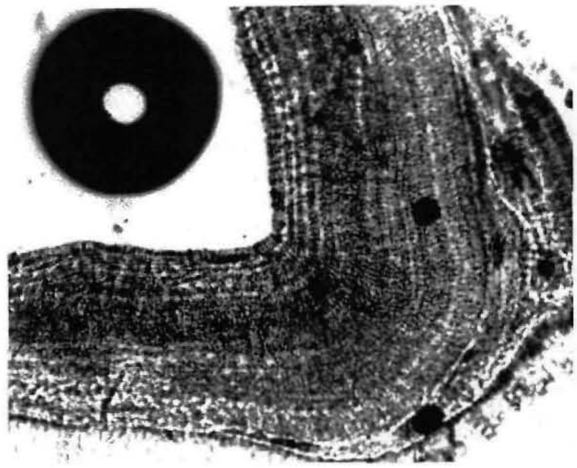
Seal shark, BSH61, 102 cm female

Seal shark, BSH14, 143 cm female

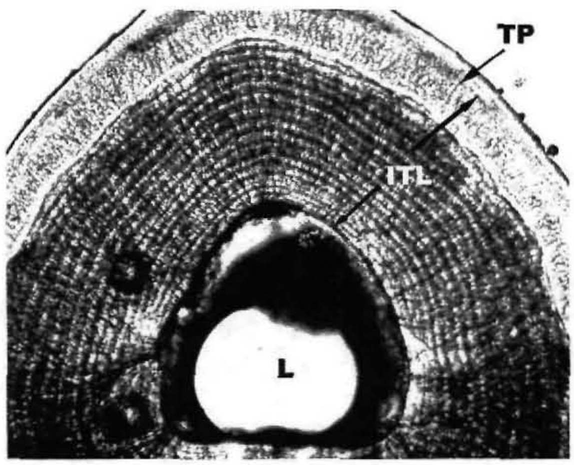
Figure 13: X rays of whole vertebrae (left), and thick sections of half vertebrae (right) from three deepwater shark species.



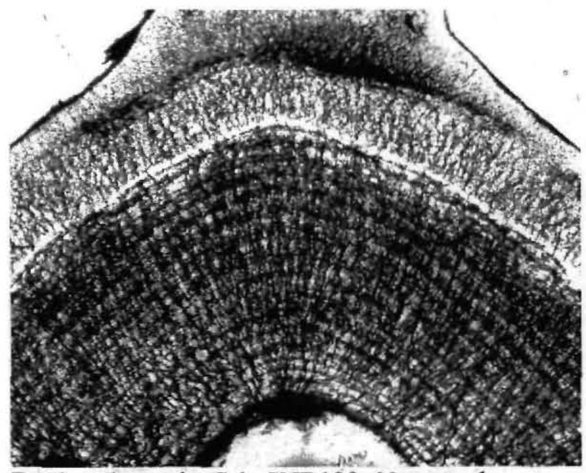
A. Shovelnose dogfish, SND43, 65 cm female



B. Shovelnose dogfish, SND43, 65 cm female (enlargement of A)

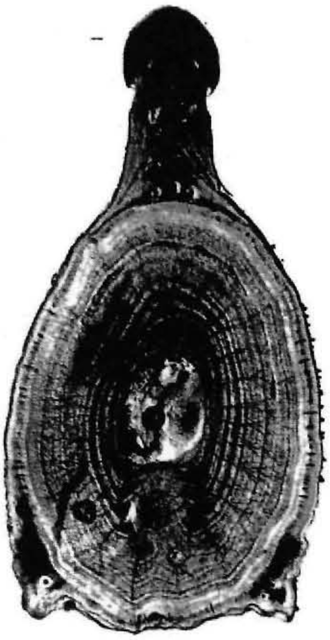


C. Shovelnose dogfish, SND130, 82 cm male

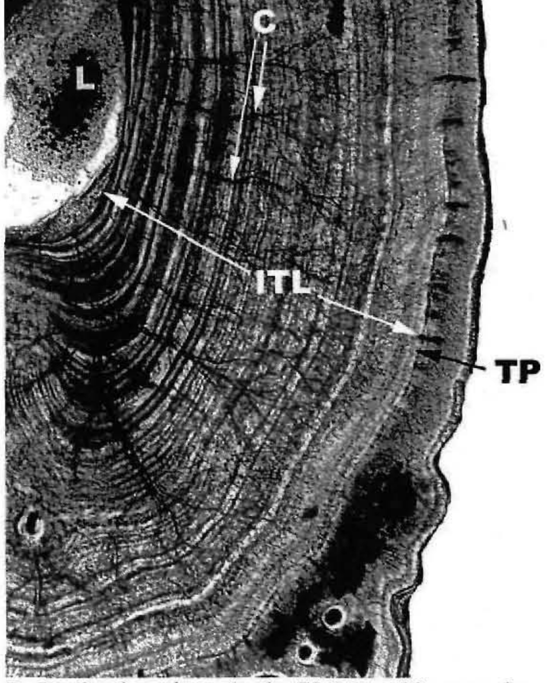


D. Shovelnose dogfish, SND130, 82 cm male (enlargement of C)

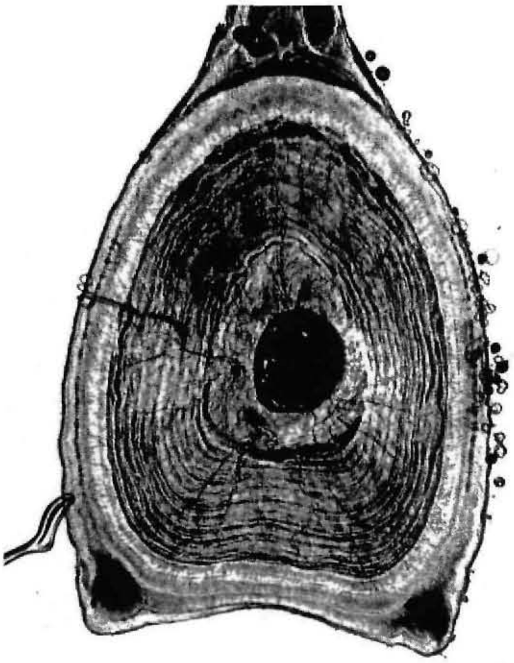
Figure 14: Thick sections from dorsal fin spines of shovelnose dogfish illuminated with transmitted white light. L = lumen; TP = trunk primordium; ITL = inner trunk dentine layer.



A. Leafscale gulper shark, CSQ22, 102 cm male



B. Leafscale gulper shark, CSQ22, 102 cm male (enlargement of A)



C. Leafscale gulper shark, CSQ4, 130 cm female

D. Leafscale gulper shark, CSQ4, 130 cm female (enlargement of C)

Figure 15: Thick sections from dorsal fin spines of leafscale gulper shark illuminated with **transmitted white light. L = lumen; TP = trunk primordium; ITL = inner trunk dentine layer; C = canaliculi.**

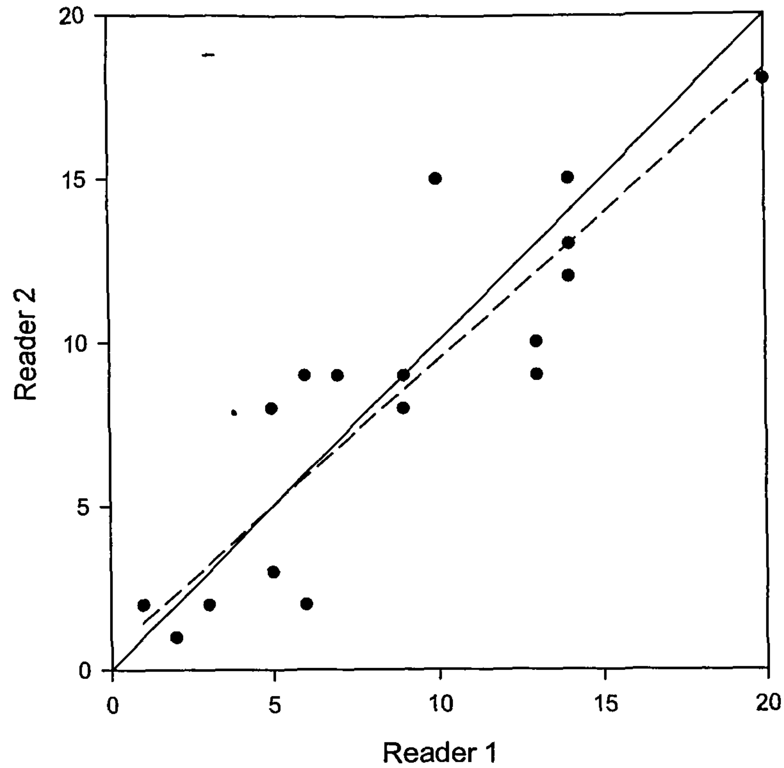


Figure 16: Comparison of band counts by Reader 1 and Reader 2 for shovelnose dogfish dorsal fin spine sections. The solid line is the 1:1 line, and the dashed line is a linear regression fitted to the data. $N = 22$.

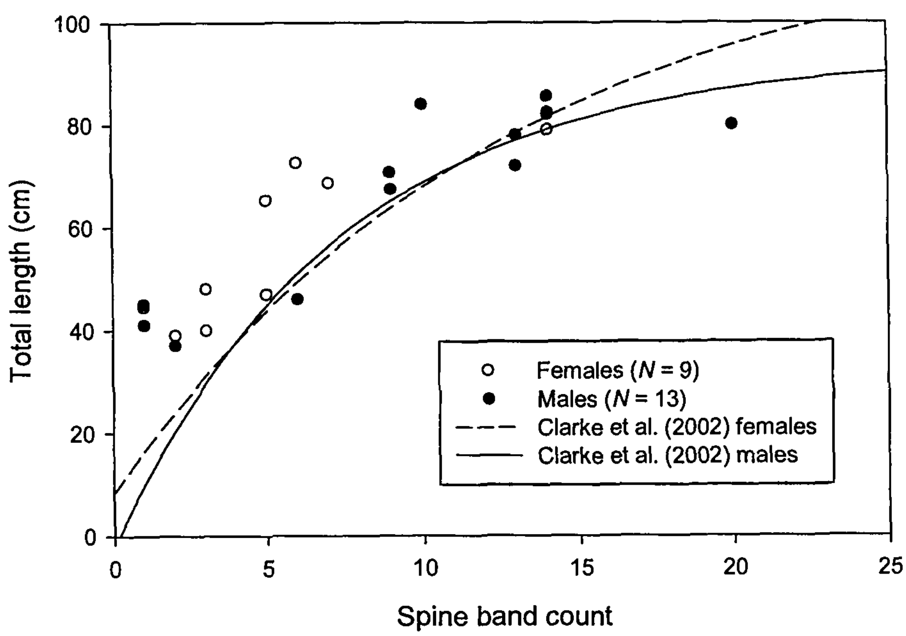


Figure 17: Relationship between total length and number of bands on the dorsal fn spine for shovelnose dogfish (Reader 1). Growth curves are also plotted for northeastern Atlantic *Deania calcea* from Clarke et al. (2002b).

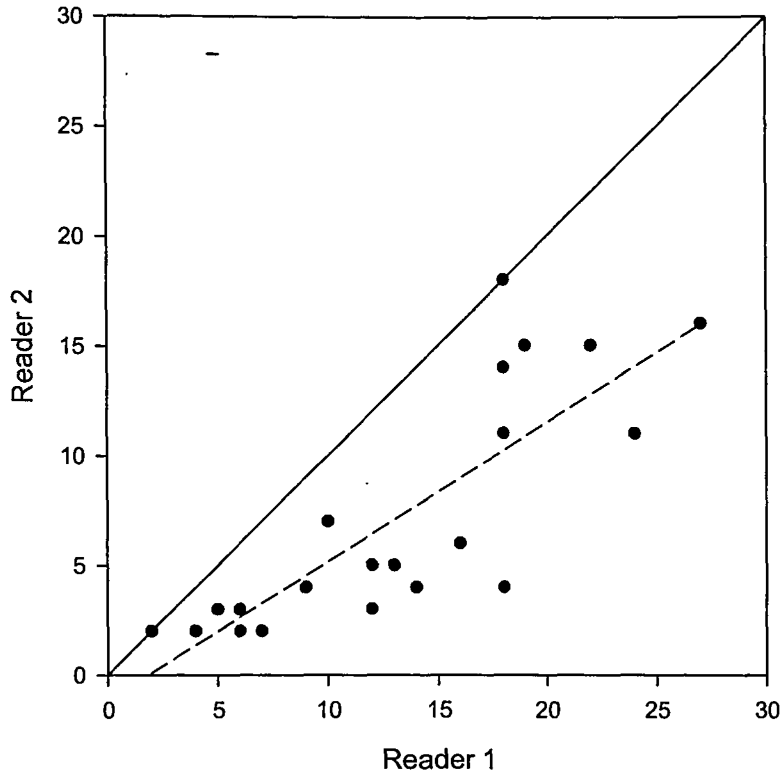


Figure 18: Comparison of band counts by Reader 1 and Reader 2 for leafscale gulper shark dorsal fin spine sections. The solid line is the 1:1 line, and the dashed line is a linear regression fitted to the data. *N* = 22.

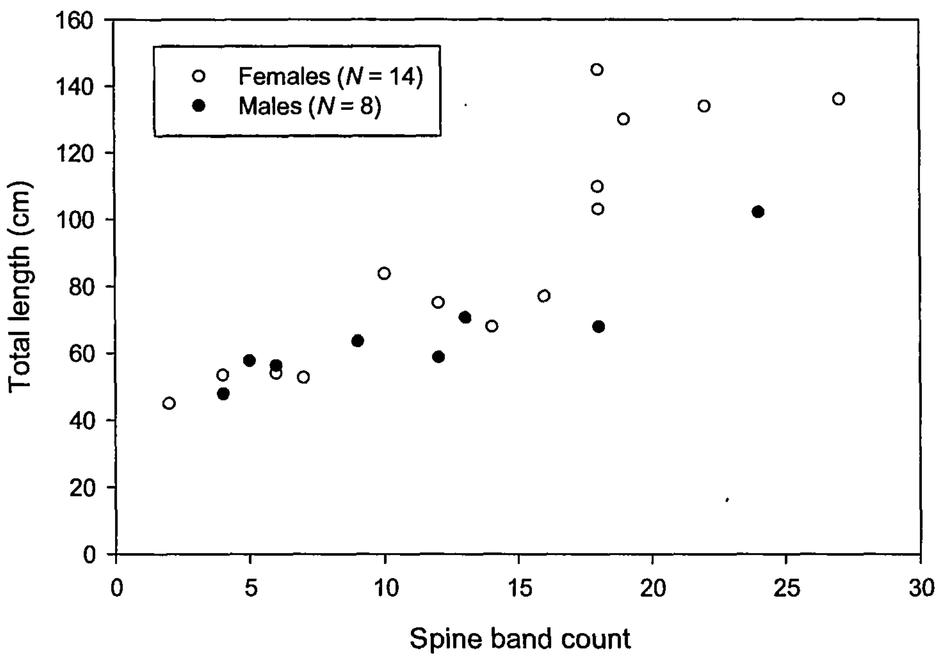


Figure 19: Relationship between total length and number of bands on the dorsal fin spine for leafscale gulper shark (Reader 1).

12. Discussion

Length-frequency data for all three deepwater shark species suffered from a number of problems that ruled out any rigorous analysis of modal structure, and therefore determination of age compositions and growth rates. Some of the problems resulted from small sample sizes and the unavailability of representative samples of the population. These problems could be overcome, with some difficulty, by more comprehensive sampling over larger regions of the Exclusive Economic Zone. More problematic, for shovelnose dogfish at least, is the lack of modal progression of the 0+ mode during the year. This probably results from the lack of a distinct pupping season (Clark & King 1989; Daley et al. 2002). It is therefore unlikely that clear modes representing distinct age classes would be visible in samples even if they were representative of the whole population. It appears that, for shovelnose dogfish at least, length-frequency analysis is unlikely to be useful for estimating growth rate and age composition.

Frequency distributions of eye lens diameters and weights of the three species showed some promise for identifying age classes, but their utility could not be determined in this study because of small sample sizes.

Vertebrae of all three shark species were poorly calcified and lacked distinct banding patterns. For the few vertebrae with visible bands, band counts were always lower than on the dorsal fin spines of the same specimens; we judged the latter more likely to be correct, and concluded that vertebral counts are unreliable as age estimates.

Fin spines sectioned transversely and viewed with transmitted white light produced the most promising results for shovelnose dogfish and leafscale gulper shark (seal sharks lack fin spines). The spine sections had more-or-less distinct concentric bands that are presumably deposited annually; the same banding structure has been used to age these two species in the northeastern Atlantic, based on an assumption of annual banding (Clarke et al. 2002a, b).

For shovelnose dogfish, the two readers had moderately good agreement overall in band counts, albeit with considerable variability for individual sharks. Considering that neither reader had had previous experience ageing these sharks, and that the two readers did not compare results or attempt to develop an agreed ageing protocol, we believe that ageing shovelnose dogfish from dorsal fin spines is highly feasible.

Growth curves for male and female shovelnose dogfish from the northeastern Atlantic are plotted over our data for comparison in Figure 17. Our data lie above the Atlantic curves, though this may be an artifact of technique: Clarke et al.'s (2002b) growth curve was a composite derived from their own adult data collected from near Ireland, and data from juveniles collected near Portugal by Machado & Figueiredo (2000). The resulting curves produced lengths at age zero (i.e. birth) of about 10 cm for females and 0 cm for males (Figure 17). These lengths are inconsistent with the known length at birth of about 28–35 cm (King & Clark 1987; Last & Stevens 1994; present study Figure 2). Thus the left-hand ends of the two Atlantic growth curves are too low. The maximum age reported for Atlantic shovelnose dogfish was 35 years (Clarke et al. 2002b) compared with our greatest band count of 20; however the largest shark in our sample was only 85 cm TL, compared with a maximum length for this species exceeding 120 cm (see Figures 1 and 2).

For leafscale gulper shark, the two readers produced substantially different spine band counts. This may reflect the difficulty of reading these sections, and inexperience with this species. Counting precision and accuracy typically improve with experience. Reader 1's counts, which gave a maximum of 27 bands for a 136 cm TL shark (Figure 19), were more consistent with those of leafscale gulper sharks from the northeastern Atlantic, where most sharks of 100–120 cm TL were estimated to be 20–40 years old (with a maximum age of 70 years) (Clarke et al. 2002a).

We conclude that band counts on sections of dorsal fin spines offer a feasible method for ageing shovelnose dogfish and leafscale gulper shark. However, further development of the technique is required, particularly in the following areas:

- Examination of larger samples so that the interpretation of bands improves as readers gain experience
- Closer study of the process of band formation in the spine lumen of large animals, in an attempt to determine whether deposition ceases or bands become too narrow to be resolved in large animals, thus leading to under-estimation of age
- Use of longitudinal spine sections to determine the best location for making transverse sections (Tanaka 1990)
- Development of ageing protocols
- Validation of annual deposition of the bands

Subject to these caveats, and taken in conjunction with studies from the Atlantic Ocean, our spine band counts indicate that shovelnose dogfish and leafscale gulper shark are slow growing and long-lived. We are unable to provide any estimates of the growth rate and longevity of seal shark.

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14. Publications

Nil.

15. Data Storage

The data have been stored on the MFish *age* database.

Appendix 1: Length-frequency measurements of shovelnose dogfish from trawl surveys.

Voyage	Region	No. measured
kah9604	Bay of Plenty	3
aex8701	Challenger	76
arr8401	Challenger	7
jco8405	Challenger	129
jco8702	Challenger	24
jco8902	Challenger	43
aex9801	Chatham Rise	117
aex9901	Chatham Rise	89
aex0101	Chatham Rise	11
tan9708	Chatham Rise	20
tan9713	Chatham Rise	8
tan9801	Chatham Rise	309
tan9807	Chatham Rise	914
tan9812	Chatham Rise	359
tan9901	Chatham Rise	500
tan9908	Chatham Rise	10
tan0001	Chatham Rise	911
tan0011	Chatham Rise	50
tan0101	Chatham Rise	1104
tan0201	Chatham Rise	1536
tan0208	Chatham Rise	138
tan0213	Chatham Rise	4
tan0301	Chatham Rise	865
tan0401	Chatham Rise	713
kah0209	Cook Strait	6
kah0308	Cook Strait	3
tan0111	Cook Strait	8
gal8603	East coast North Island	142
ora0301	East coast North Island	60
tan0109	East coast North Island	498
tvi0101	East coast North Island	44
jco7903	East coast South Island	64
wnk8501	North Island	879
wnk8502	North Island	1510
wnk8503	North Island	1757
wnk8604	North Island	2456
wnk8605	North Island	1406
tan0012	Subantarctic	93
tan0118	Subantarctic	408
tan0219	Subantarctic	331
tan0317	Subantarctic	201
tan0007	West coast South Island	176

Appendix 2: Length-frequency measurements of leafscale gulper sharks from trawl surveys.

Voyage	Region	No. measured
jco8405	Challenger	1
aex0101	Chatham Rise	12
aex9801	Chatham Rise	1
aex9901	Chatham Rise	2
tan9609	Chatham Rise	1
tan9705	Chatham Rise	3
tan9708	Chatham Rise	3
tan9807	Chatham Rise	34
tan9812	Chatham Rise	5
tan9908	Chatham Rise	8
tan0201	Chatham Rise	4
tan0208	Chatham Rise	57
tan0301	Chatham Rise	15
tan0401	Chatham Rise	14
kah9911	Cook Strait	4
kah0107	Cook Strait	1
kah0209	Cook Strait	13
kah0308	Cook Strait	13
tan0111	Cook Strait	28
tan0109	East coast North Island	2
tvi0101	East coast North Island	1
wnk8502	North Island	7
wnk8605	North Island	6
aex8902	Subantarctic	29
tan0118	Subantarctic	4
tan0219	Subantarctic	82
tan0317	Subantarctic	28
tan0007	West coast South Island	44

Appendix 3: Length-frequency measurements of seal sharks from trawl surveys.

Voyage	Region	No. measured
jco8405	Challenger	13
aex9801	Chatham Rise	4
jco7903	Chatham Rise	10
tan0011	Chatham Rise	2
tan0208	Chatham Rise	2
tan0301	Chatham Rise	55
tan0401	Chatham Rise	66
tan9807	Chatham Rise	12
tan9812	Chatham Rise	7
tan9901	Chatham Rise	3
tan9908	Chatham Rise	3
kah0209	Cook Strait	8
kah0308	Cook Strait	5
kah9911	Cook Strait	4
tan0111	Cook Strait	8
kah9304	East coast North Island	3
tan0109	East coast North Island	3
jco8201	East coast South Island	1
jco8106	North Island	15
wnk8501	North Island	21
aex8902	Subantarctic	1
tan0012	Subantarctic	3
tan0118	Subantarctic	4
tan0219	Subantarctic	10
tan0317	Subantarctic	15
wes7902	Subantarctic	9
tan0007	West coast South Island	33