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Stomach content analyses of deepwater sharks taken by benthopelagic trawls in the Southwest Indian Ocean

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Abstract

Stomach-content data for deepwater sharks in the Southern Indian Ocean are largely unavailable, limiting the scope of knowledge of trophic impacts of SWIO trawl fisheries and SIOFA-managed ecosystems. This study analyzed stomach contents from sharks collected as bycatch during commercial fishing operations onboard the F.T. Will Watch in 2012 and 2014 across the Southwest Indian Ocean Ridge, Walters Shoal, and Madagascar Ridge. Of 3,493 sharks examined, 204 individuals (12 species) contained identifiable prey remains (4.85%). Across all non-empty stomachs, teleosts dominated the observed diet (70.9%), followed by cephalopods (22.8%), crustaceans (3.2%), mammals (1.9%), and sharks (1.3%). Species-level patterns were broadly consistent with published diet information for several taxa, while uncommon prey categories were observed in some species (including mammal and crustacean remains in Centroselachus crepidater). Anthropogenic artifacts (clean cuts) were apparent on some fish remains and attributable to vessel offal, indicating fishery-derived food inputs to scavenging deepwater sharks. Because observations were based on visual inspection at sea, and most stomachs were empty or highly digested, results should be interpreted as baseline trophic signals rather than definitive quantitative diet estimates. Nonetheless, these data provide new regional evidence on deepwater shark feeding ecology in the SIOFA Area and highlight priorities for follow-up work using retained specimens and molecular diet methods to improve prey resolution and ecosystem-level inference.

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STOMACH CONTENT ANALYSES OF DEEPWATER SHARKS TAKEN BY BENTHOPELAGIC TRAWLS IN THE SOUTHWEST INDIAN OCEAN

Paul Clerkin[3]
Doctoral Researcher at the Virginia Institute of Marine Science
Director of Research for Deep Blue Research Foundation
&
R. Shotton
Southern Indian Ocean Deepsea Fishers Association

1. INTRODUCTION

Little is documented on the nature of the stomach contents of deepwater sharks caught in the Southwestern Indian Ocean. For example, Chazeau *et al.*(2019), in a detailed study of deepwater shark bycatch in the Kerguelen area over an eleven-year period, reported no stomach contents analyses. Cherel and Duhamel (2004) provide observations on two deepwater species, "small lanternsharks (*Etmopterus* cf. *granulosus*; 0.3m on average)", subsequently described as *E. viator*, and "the huge sleeper sharks (*Somniosus* cf. *microcephalus*; 3.9 m)"— presumably *Somniosus antarcticus*. Dunn *et al.* (2010) reported on the diets of several species caught during three research trawl surveys on Chatham Rise, east of New Zealand— *Dalatias licha*, *Centrophorus squamosus*, *Centroscymnus owstonii*, *Centroselachus crepidater* and *Proscymnodon plunketi*— which are also caught in the Southwest Indian Ocean.

2. METHODS

In 2012 and 2014, during two trips and 113 days at sea by the F.T. *Will Watch,* a deep-sea factory trawler owned by United Fame Investments Ltd of the Cook Islands, 3493 deep-sea sharks were caught. Fishing was undertaken on the Southwestern Indian Ocean Ridge (SWIOR) and the Madagascar Ridge, including the relatively shallow Walters Shoal. The trips were from 1 March to 23 April 2012 (54-days) and 10 April to 7 June 2014 (59-days) in the area 29˚34'–40˚40'S; 43˚10'—55˚15'E.

Bentho-pelagic tows were undertaken at 46 stations by 427 tows along the Southwest Indian Ocean and Madagascar ridges starting from 200 m and finishing at no more than 1400 m. A roller-equipped rock-hopper bentho-pelagic demersal trawl with reported dimensions of 15 m mouth width, 50 m wing span, and 5 m height was used or a mid-water bentho-pelagic trawl with reported dimensions of 80-100 m wing span and 35 m headline height. Both the demersal and pelagic trawls had a 110 mm stretched mesh cod-end. The pelagic trawls were towed approximately 2 m off slope surfaces.

Corresponding author: < pauljclerkin@gmail.com> [3]

Sharks were captured in 138 demersal and 78 mid-water tows. There were 114 tows on Madagascar Ridge including seven in the northern region, 97 tows on Walters Shoal in the southern region and 112 tows on the Southwest Indian Ocean Ridge. A total of 31 species from 14 genera were identified.

The stomach contents of all specimens were examined. The study had no capacity to retain stomach contents for detailed analysis and the information obtained was derived from visual inspection only. With the exception of specimens retained for museum collections, and when large catches of *Etmopterus. granulosus* did not allow for it, all stomachs were examined.

3. RESULTS

Species were identified and sex ratios, length, maturity, reproduction and distribution of the 31 species/ 14 genera that were recorded. A total of 204 individuals from 12 species were found to have identifiable food items in their stomachs (Table 1, Figure 6) – 4.85% of stomachs examined. Many specimens had digested fluid contents and it is a common occurrence for fish to void stomachs contents when the gear is recovered from great depths.

The diet composition for these sharks was chiefly teleosts - bony fish represented 70.9% of stomach contents. Squid was the next most common food item - 22.8% of stomachs, then crustaceans (3.2%), seals 1.9%, and sharks (1.3%). Prey were usually within the known food items for all species with the exception of crustacean and seal remains found in *C. crepidater*. Table 2 lists species found with stomach contents, prey items given by number and percentage composition of estimated value, compared to diet reported in the literature.

Centrophorus granulosus stomachs contained only bony fishes as reported by Compagno (1984) for other areas. One specimen of a *C. squamosus* stomach contained cephalopod remains consistent with the reports of Macpherson (1989); Last and Stevens (1994) and Ebert (2013). *Deania calceus* examined in this study contained bony fish and cephalopods, consistent with that found by Compagno *et al.* (1989). The stomach contents of adult *Deania profundorum* had bony fish and squid, consistent with Ebert *et al.* (1992).

Etmopterus granulosus contained a wide variety of bony fishes and cephalopod similar to that reported by Compagno *et al.* (1989). Of the 61 individuals containing stomach contents, 39 (66%) contained bony fishes and 20 (33%) cephalopods. Only two individuals had fish and cephalopod remains in their stomachs. Visual estimates indicated that fish constituted 70% of stomach contents. Males fed mostly on cephalopods (80%); only a single male (63 cm TL) had fish in its stomach. Females largely fed on fish (88.9%). Contents often consisted of large pieces or whole animals.

Scymnodon plunketi stomach contents consisted mainly bony fishes - 14 (82.4%) individuals contained only fish, one (5.9%) contained cephalopods, and two (11.8%) contained fish (66% and 80% by volume) and cephalopods (34% and 20% by volume). Ebert (2013) also found this species preyed on cephalopods.

Centroscymnus coelolepis stomach contents included bony fish, cephalopods, consistent with Last and Stevens (1994) and Compagno *et al.* (1989) and seal blubber, two sharks with fur still attached to the food item.

Centroscymnus owstonii stomach contents consisted of cephalopods, bony fishes, as reported by Last and Stevens (1994) - cephalopods in one male, bony fishes in two females, and a combination of cephalopod (75%) and fish (25%) in one female. *Centroselachus crepidater,* stomach contents, found in 30 individuals, contained fishes, cephalopod, crustacean, and one shark contained seal remains.

One shark had both crustacean and fish (33% and 64% respectively by volume) and another had cephalopod and fish (50% respectively by volume). While fish and cephalopod have been recorded in the literature this is the first account of crustacea and seal in this species' diet.

Sixty five *Dalatias licha* stomachs were examined: they contained mainly bony fishes - 50 (76.9%) individuals contained only fish, three (4.6%) squid, three (4.6%) shark, and one (1.5%), invertebrates. Wetherbee *et al.* (1990) found similar results . Mixed contents were found in 8 (12.3%) individuals, consisting, by volume, on average 19% shark, 35% squid, and 46% squid. There was no apparent correlation between sex, length, maturity and stomach contents composition.

Pseudotriakis microdon stomach contents contained fish and crustaceans in two specimens, consistent with that found by Yano and Musick (1992).

Chimaera willwatchi stomach contents included bony fish and bivalves, as evident by the presence of scales and crushed shells. This is the first observation on diet for *Chimaera willwatchi*, but benthic invertebrates are common prey of all chimaeroids studied to date. A few species – *C. monstrosa*, *Hydrolagus bemisi*, *H. colliei*, *H. novaezealandiae*, *Harriotta raleighana* are known to prey on small fish (Didier *et al.*, 2012; Dunn *et al.*, 2010). There was no apparent relation between diet composition and sex, maturity, or length of individual for any species, and it appears diet might be taken opportunistically. (Grubbs, 2010).

4. DISCUSSION

Only a relatively small number of sharks found had food in their stomachs - 204 individuals from around 4000 stomachs examined. This could be the result of emptying of their stomachs during gear retrieval as not only would there be probable physical jostling of the sharks in the net but also enormous barometric changes. Thus, these results likely provide only an insight into actual deepwater shark diets and feeding behaviour.

The occurrence of fish offal in several species including *Centrophorus granulosus* and *Pseudotriakis microdon* stomachs was of particular interest. The fish heads were partially digested and almost certainly came from offal discarded from the factory trawler processing alfonsino (*Beryx splendens*) and orange roughy (*Hoplostethus atlanticus*) she targeted in the area. This conclusion was strengthened by some fish heads clearly showing the straight cuts from processing by heading and gutting (H&G) machinery (Figure 1). Figure 2 shows the contents taken from the stomach of a single *Pseudotriakis microdon* – what look like discarded orange roughy heads, again removed by fish processing equipment and a crab, possibly the Gerionid *Chacaeon* sp. (*notialis*?)

Figure 1. Two alfonsino heads and a further unidentifiable head removed by processing machinery and discarded, found in a *C. granulosus*.

Figure 2. Orange roughy heads and a deepwater crab (*Chaceon* sp. taken from a *Pseudotriakis microdon.*

Sanders (2023) from field studies of the same fishery in 2009, reported that the stomachs of several *Centroscymnus owstonii* contained distinct pieces of fish offal, i.e. "large pieces of the central spine with the tail attached, as would also have been produced by a filleting machine". Offal from bentho-pelagic trawling would provide a large source of food and thus energy for growth and reproduction for the shark species eating this material.

Also of interest was the finding of bivalve shells in the stomach of *Chimaera willwatchii*, and more particularly, where did these shells come from? The depths at capture for these specimens ranged from 850 m–1365 m for both sexes, i.e. very deep waters. The first assumption would be that bivalves inhabit these depths, though there is no record of such occurrences.

Cherel & Duhamel (2004) reported that the small lantern sharks (*Etmopterus* cf *granulosus*) of their study fed on small sizes of the whip-lash squid, *Mastigoteuthis psychrophile*, which grows to 14 cm.

Dunn *et al.* (2009) found that the prey of *D. licha*, *C. squamosus*, and *P. plunketi* were predominantly benthic or demersal fishes and cephalopods. The prey of *C. owstonii* and *C. crepidater* were predominantly mesopelagic fishes and squids. These authors noted that scavenging of discards from commercial fishing vessels was likely by *C. squamosus* and *P. plunketi.*

Figure 3. A recovering/recovered orange roughy that has been attacked on its dorsum. The width of the bite may provide an indication of the size of the presumed shark that attacked the orange roughy. This specimen was approximately 60 cm total length, which allows a visual estimate of the width of the bite of ≈ 15 cm.

The catch of orange roughy by the F.T. *Will Watch* also showed a phenomenon well known to crews for these fisheries in the Southern Indian Ocean (see, e.g., Sanders 2023). A small number of orange roughy that are caught show a body segment had been removed from their dorsal margin (See Figure 3). It is assumed that this was caused by a shark bite. Sanders (2023) notes that fresh wounds on orange roughy were only seen when kitefin sharks (*Dalatias licha*) were caught and had evidently bitten the orange roughy while in the net. This may not have been a feeding attack.

The widespread and continuing presence of orange roughy that have recovered from such bites raises the issue of how extensive is, presumably, shark attack, and predation, on this species and its

importance as a food source for sharks. A reasonable assumption is that such attacks would commonly be fatal and if the orange roughy did not escape it would be entirely consumed. Figure 4 allows an estimate of the gape of the (presumably) shark that bite this orange roughy, and indicates a gape of approximately 20 cm. This would be larger than any of the shark species commonly found in the deepwater shark catch reported here. However, such bites can be smaller (see Figure 5) giving rise to the possibility that this type of feeding attack is undertaken by more than one species or shark size.

Figure 4: Dimensions of bite.

While this study only investigated diet composition in terms of broad taxonomic categories, it is a step towards better establishing the known diets of Indian Ocean sharks, which is vital to understand the ecological roles of these top predators and their response to changes, anthropogenic or otherwise, in their environment. The information included in this paper contributes to a basic picture of the diet of deepwater Indian Ocean sharks and we suggest a more detailed investigation in the future. Given the majority of stomach contents were in advanced state digestion, an eDNA analysis of shark diet may be suitable for future work.

Figure 5: Orange roughy showing a healed bite segment that was relatively small. Again assumed to be a shark bite.

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	Sample size	Food items		Known Diet	Citations
Centrophoridae					
Centrophorus granulosus	6	8 fish	100% fish	fish, Ceph, crust.	Compagno, 1984; Ebert, 2013
Centrophorus squamosus	1	1 Ceph	100% Ceph	Presumably feeds on fish, Ceph	Macpherson, 1989; Last and Stevens, 1994; Ebert, 2013
Deania calcea	3	1 Ceph, 3 fish	25% Ceph, 75% fish*$^{\beta}$	fish, Ceph	Compagno *et al.*, 1989
Deania profundorum	2	1 Ceph, 1 fish	50% Ceph, 50% fish*$^{\varphi}$	fish, Ceph	Ebert *et al.,* 1992
Etmopteridae					
Etmopterus granulosus	60	21 Ceph 40 fish 1 crust.	25.5% Ceph, 71.2%fish, 1.7% crust.	fish, Ceph	Compagno *et al*., 1989
Somniosidae					
Scymnodon plunketi	18	3 Ceph, 17 fish	8.6% Ceph, 91.4% fish	fish, Ceph	Ebert, 2013
/Centroscymnus coelolepis	7	2 mammal, 2 Ceph, 2 fish, 1 Unid	*$^{\delta}$	fish, Ceph, , gastropods	Last and Stevens, 1994; Compagno et al., 1989
Centroscymnus owstonii	4	4 Ceph, 3 fish	50% Ceph, 50%fish	fish, Ceph	Last and Stevens, 1994
Centroselachus crepidater	30	1mammal, 2Ceph, 29 fish, 2 crust.	3.3% mammal, 5% Ceph, 87.2% fish, 4.4% crust.	fish, Ceph	Compagno, 1984; Macpherson, 1989; Last and Stevens 1994
Dalatiidae					
Dalatias licha	65	5 shark, 9 Ceph, 61 fish	7.1% shark, 9.1% crust., 82.5% fish	fish, shark, Ceph, and other invertebrates	Wetherbee et al., in 1990
Pseudotriakidae					
Pseudotriakis microdon	7	11 fish, 2 crust.	25% crust., 75% fish *	fish, Ceph	Yano and Musick, 1992
Chimaeridae					
Chimaera willwatchi	1	fish and crust.*$^{\gamma}$	Not examined internally	genus consumes fish and invertebrates	Didier et al., 2012; Dunn et al., 2010

Abbreviations:

Ceph=Cephalopod, Crust=Crustacean, Unid= Unidentified

*$^{\beta}$ 1 specimen with Ceph: fish 50:50, and the other two with 100% fish.

*$^{\delta}$No mixed diets.

*$^{\approx}$ One Crustacean 50:50, others 100%

*$^{\gamma}$Fish scales and bivalve shells. Not examined internally. Count and volume not obtained.

Figure 6. Prey items as item-count percent composition for each species encountered with stomach contents. Broad taxonomic prey groups are: cephalopod (red), fish (blue), crustacean (pink), mammal (orange), shark (grey), and unidentified (black).