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Distribution and Biology of Orange Roughy (*Hoplostethus atlanticus* Collett 1889) in the Northwest Atlantic

by

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Abstract

The first confirmed record of orange roughy from the continental slope of the northwest Atlantic was a 45.8 cm (fork length) female specimen taken in Nov. 1982 by a Canadian fishery observer on a Russian vessel directing for Greenland halibut at Lat. 60°41' Long. 61°08' in 980 m. From 1991 to 2000, fishery observers recorded a further 505 specimens from 217 sets for various fleets fishing on the slope waters off Canada. Previously observed east of Greenland, the range of orange roughy was extended from the slope waters off southwest Greenland to the southwest Scotian Shelf. They were found to be more concentrated to the north centred at Lat 60°, primarily at depths exceeding 800 m and associated with the warmest available bottom temperatures. None were found in less than 2°C. The size (total length) of orange roughy taken in the present study ranged from 39.5-62.5 averaging 54.6 cm. This sample of 27 fish was not inconsistent with orange roughy lengths taken in the northeast Atlantic where they range between 15 and 75 cm, the majority between 50 and 70 cm. Detailed characteristics, morphometrics and meristics of orange roughy were consistent with other areas. One specimen had a patch of vomerine teeth but corresponded with *H. atlanticus* in all other features. The length-weight relationships are similar to those reported from west of Britain off Faroe Is., Iceland and on the Mid Atlantic Ridge. Length conversion factors are essentially the same as those obtained from west of Britain and off Iceland. Based on a small sample size of fish taken prior to the late winter spawning period observed for the northeast Atlantic, all females over 38.5 cm SL were deemed mature, those smaller were likely immature. One female was ripening whereas the other large females appeared to be spent or recovering, although some of these contained eggs large enough to be seen by the naked eye. All males, with the possible exception of the two fish with the smallest testes, were mature. Several, taken in October-November, appeared to be ripening. Although few stomachs were examined, those indicated that diet in the Northwest Atlantic is similar to that in the Northeast Atlantic in its dependence on benthopelagic decapod crustaceans (pasiphaeid shrimp including *Pasiphaea tarda*), fish (one notosudid, *Scopelosaurus lepidus*) and cephalopods (beaks). Distribution patterns and other consistencies suggest that northwest Atlantic orange roughy are a western fringe component of the northeast Atlantic population.

Introduction

Orange roughy (*Hoplostethus atlanticus*, Beryciformes Trachichthyidae, Fig 1) is a widely distributed deepwater species inhabiting the slope waters and seamounts of the Atlantic, Indian and Pacific Oceans. Branch (in press) provides a global review of the distribution, biology and fisheries for this species. It was first identified from a specimen off the Azores in the north Atlantic (Collett 1889) but has subsequently been found in varying concentration west and south of Iceland including the mid-Atlantic Ridge and Corner Seamount (Hareide and Garnes, 2001; Magnússon, 1998; Magnússon and Magnússon, 1995; Vinnichenko, 1997), along the slope of the

eastern Atlantic (Bridger, 1978; Ehrich, 1983; Mauchline and Gordon 1984; Merrett and Wheele,r 1983; Pechenik and Troyanovskii, 1970), around south Africa, into the Indian Ocean (Kotlyar, 1980) and onto to the shelf slopes of south Australia and New Zealand (van den Broek and Tracey, 1981; Liwock and Linkowski, 1986). Worldwide, it is generally reported to be most abundant at depths exceeding 800 m often associated with seamounts and rises (Hareide and Garnes, 1998). The exception is off Namibia where the fish concentrate in 600-800 m (Branch in press).

Although first recorded in the Atlantic (Collett 1889) orange roughy was initially exploited in the south Pacific. In the late 1970's, a fishery was developed on the seamounts of New Zealand (Coburn and Doonan, 1994). It evolved into an important commercial fishery with catches peaking at about 50,000 t in the early-1980s. Several years later, commercial concentrations were also located off southern Australia (Bulman and Elliott 1994). Those virgin stocks were quickly fished down in a number of areas and this species has since become the object of intense fisheries management in both New Zealand and Australia (Annala, 1996; Bulman *et al*., 1994; Clark, 1995; Clark at al., 2000; Clark and Tracey, 1994; Coburn and Doonan, 1994; Francis and Smith, 1995; Grant *et al*., 1999). Rapid declines in the newly exploited populations was the norm for this slow going, long lived species leading Clark (2001) to ask the whether fisheries were sustainable for this or other deepwater species.

In the north Atlantic, Pechenik and Troyanovskii (1970) considered orange roughy as a potential fishery resource Bridger (1978) and Ehrich (1985) reported on concentrations over deep slope waters west of Britain. However, it was not exploited in this area until years later, long after the commencement of the south Pacific fisheries. In the late-1980s orange roughy were found in sufficient concentrations off the coast of Britain to be pursued commercially. Thomsen (1998) reported that orange roughy appeared as a new species in the European market in 1991 although the landing statistics of France indicated small amounts as early as 1989 (Charuau *et al*., 1995). Hareide and Garnes (1998) subsequently reported that roughy was widely distributed over portions of the mid-Atlantic Ridge (Iceland to the Azores) sometimes in dense concentrations. The largest concentrations were found off the Azores in 800-1200 m. Iceland has fished orange roughy since 1991 (Magnússon, 1998) and an experimental fishery has been carried out since 1992 by the Faeroes (Thomsen, 1998). That fishery exploited concentrations on deep-sea banks and pinnacles in the western and southern area in Faeroese waters, in the Hatton Bank area and on the Mid-Atlantic Ridge between the EEZ's of Iceland and the Azores. Most of these Atlantic fisheries reported rapid declines in the concentrations soon after the commencement of fishing, similar to what was observed in the Pacific.

Orange roughy, although a valuable commercial species elsewhere has never been the target of exploitation in the northwest Atlantic. The Canadian fishing industry, in observing the exploitation of orange roughy in the northeast Atlantic have expressed an interest in the status of the species in the northwest. Previously, the closest records of occurrence of orange roughy to Canadian waters are from the east coast of Greenland and the corner Seamounts south of the Grand Banks. The purpose of this paper is to present information on this species from slope waters off the coast of Canada. Both fishery observer records and research survey vessel records were examined for incidences of the species. Their distribution was described in terms of season, depth and bottom temperature. Gonads and stomachs were examined from a subset of the specimens and morphometric and meristic characteristics were compared to studies in other areas.

Methods

Fishery observers collect geo-referenced (latitude and longitude) information on the catch, effort and other details of various commercial fisheries in a manner specified in Kulka and Firth (1987). The catch of all species taken in the gear is included in the records along with a geo-reference (latitude and longitude), depth and time. Fishery observers were provided with colour photographs of orange roughy and where possible, the observers were instructed to return frozen specimens to Fisheries and Oceans to verify species identification. From 1991-2000, 202,741 observed commercial sets were observed for otter trawl, shrimp trawl, longline and gillnet fisheries. These sets yielded a total of 505 orange roughy from 217 sets. Several other gears observed are not included in this analysis as they were deployed in shallow near shore locations only. Twenty-six specimens plus the original 1982 record were returned to the lab for detailed analysis. The Canadian research surveys were also examined back to 1951 but no records of orange roughy were found.

The analyses were done for the period 1991-2000 when fishery observers were instructed to record all records in the catches observed. SPANS GIS (Anon, 1997) was used to map the distribution of the orange roughy records and to

analyse these records in terms of bottom temperature. Given the rarity of records in the area examined, data from all years were combined. Expanding symbols in the form of crosses proportional to the number of orange roughy in the catch were used to depict distribution. As well, the ratio of number of sets containing orange roughy to total sets fished by gear was calculated for the area north of Lat. 55° and compared to the area south of Lat. 55°. Sets with orange roughy were examined in relation to depth and month and were also laid over a surface of long-term (1972-1999) bottom temperature means.

Twenty-seven specimens were frozen and returned to the lab for further analysis. They were measured for 11 morphometric characteristics and 16 meristic counts according to Woods and Sonoda (1973) and Merrett and Wheeler (1983). Not all fish were measured for all characteristics. Table 3 specifies the various measures taken. Using these measurements and counts facilitated comparison of the northwest Atlantic fish with those in other parts of the world. Averages and variance statistics were calculated for each characteristic and mean values and ranges were compared to other studies.

Reproductive state was observed for 24 specimens (14 females, 10 males), 19 of which were caught in August to November using states described in Du Buit (1995) and Thomsen (1998). Stomach contents were examined in 18 specimens and components were speciated where possible.

Results and Discussion

Distribution

In Nov. 1982, a fish specimen collected on a Russian vessel directing for Greenland halibut in 980 m bottom depth at Lat. 60°41' Long. 61°08' was identified as a female *H. atlanticus*, fork length 45.8 cm. This specimen is the first confirmed record of orange roughy from North American slope waters. Since then, 505 more records of orange roughy from 217 sets from commercial catches have been reported by fishery observers, some with accompanying photographs to confirm identification. Although the majority of sets observed were for the shrimp fishery, most sets with orange roughy came from the groundfish otter trawl fishery (Table 1). The previous sole record of orange roughy occurrence in the Northwest Atlantic were reported by Woods and Sonoda (1973). They listed 14 specimens from the Gulf of Maine taken by a trawler out of Rockland, Maine. However, the position recorded in that paper, Lat. 44°40' Long. 56°59' is located south of Newfoundland in the Laurentian Channel (refer to Fig. 3) and not in the Gulf of Maine. A further check of the specimens at Museum of Comparative Zoology, Harvard was not able to confirm the location of capture but was able to confirm that the specimens were orange roughy. No orange roughy have been reported from USA waters or areas south. Orange roughy from the Corner Seamount were previously reported by Vinnichenko (1997) but these seamounts are well separated from the North American Shelf 750 km due south of the continental slope (southern tip of the Grand Bank) adjacent to the western side of mid-Atlantic Ridge. The present study also reports on 8 specimens taken from the Corner Seamounts confirming the records of Vinnichenko (1997).

The 498 orange roughy from the slope waters off Canada plus the 8 from the Corner Seamount were captured in a variety of fisheries. Table 2 shows that they were taken most commonly as by-catch in the Greenland halibut (186 sets mostly in NAFO Div. 0), shrimp (Flemish Cap, Div. 3M 13 sets) and alfonsino (Corner Seamount, 7 sets) fisheries. They were also captured rarely in the witch, roundnose and roughhead and grenadier, redfish, halibut and yellowtail (one set) fisheries. This is similar to species associations in the northeast Atlantic where Hareide and Garnes (1998) reported that orange roughy were caught with roundnose grenadier, Greenland halibut, black scabbard fish, sharks, smooth-head, alfonsino, deep-sea cardinal fish and a variety other deepwater species

Orange roughy capture locations from the current study are mapped in Fig. 2a, northern distribution from Davis Strait west of the southern tip of Greenland to the Labrador Shelf and Fig. 2b, Northeast Newfoundland Shelf and the Grand Banks. The insert shows 4 records of single specimens captured at their most southern extent, on the southwest slope of the Scotian Shelf. No orange roughy were recorded in the Gulf of St Lawrence or the Bay of Fundy where it is assumed that depth is too shallow (although bottom temperatures are warm, most of the area in excess of 4°C). This species has not been reported in semi-enclosed bodies of water inside the shelf break in other parts of the world. They were recorded as far north as Lat 65° on and as far south as Lat 35° on the Corner Seamounts (Seamount records not mapped). Extensive effort directed for Greenland halibut and shrinp north of Lat

65° in deep water between Greenland and Baffin Island yielded no orange roughy and thus we have defined its northern limit in the northwest Atlantic at about Lat 65° (see the discussion on bottom temperature in this area) No data were available east of Long 58.2° along the southwest slope off Greenland but it is reasonable to presume that sets there would yield orange roughy and that density may increase eastward toward where they are found in dense concentrations. No records of orange roughy have been reported in the literature in USA waters or the Atlantic side of South America and thus the known southern limit on the North and South American slope is the Scotian Shelf. However, they have been recorded off southern Chile on the Pacific side where there is a small fishery (Branch in press).

Orange roughy records were intermittent and clustered. The clustered pattern observed in part is an artifact due to uneven fishing effort distribution. However, fishing activity did occur along the entire extent of the slope suggesting that orange roughy are concentrated at certain locations. The two most dense clusters of orange roughy sets (175 sets yielding 436 individuals) centered at Lat. 63° are associated with a Greenland halibut (*Hippoglossus hippoglosoides*) fishery. Records were fewer and more dispersed to the south. The northeast Newfoundland Shelf and Grand Banks yielded 44 individuals from 18 sets, 14 individuals from 13 sets from the Flemish Cap, 4 sets (single specimens) were recorded from the Scotian Shelf and 8 sets, 7 individuals from the Corner Seamount. As noted above, Vinnichenko (1997) had previously reported orange roughy from these seamounts but was not specific as to numbers or catch per unit effort.

Figure 3, left panel shows that most records of orange roughy came from otter trawls. A few records were taken from shrimp trawls and gillnets but none were recorded for longlines or a variety of inshore gears. The relative percent of sets with orange roughy (sets with orange roughy as a percent of total sets observed) was greater at depths exceeding 500 m. The middle panel of Fig. 3, northern area (> Lat 55° corresponding to Fig. 2a) shows the same values at all depths vs. >500 m for otter trawls because nearly all otter trawl sets in this area were prosecuted at depths greater than 500 m. Most (98%) of shrimp trawl sets to the north occurred at depths less than 500 m and yielded only 1 orange roughy (refer to discussion of depth and temperature).

Figure 3 also shows that a greater proportion of sets to the north yielded orange roughy. For the deep sets there was a substantially greater proportion of observed sets with orange roughy to the north (0.119% in the south, 0.656% in the north). Captures in other gears were too low to draw any conclusions. As well, comparing north and south in terms of number of roughy captured per set, there were a larger proportion of sets with only 1 orange roughy observed to the south (Fig. 4). With the exception of 2 sets (in the vicinity of the Laurentian Channel) all large sets (exceeding 4 individuals) were recorded to the north. This evidence further suggests that orange roughy are more concentrated to the north, their closest proximity to the northeast Atlantic concentrations located to the east between Greenland and Iceland.

Figure 5 shows that although the majority of sets with orange roughy were taken between July and November, some sets with orange roughy were recorded in all months. Orange roughy are present in the northwest Atlantic year round. The greater number of sets from July to November is related primarily to temporally concentrated fishing effort. The majority of the fishing, about 95% occurred during that period.

Figure 6 shows that in terms of depth, 96% and 92% of the orange roughy records were taken from depths greater than 500 and 800 m, respectively. This is consistent with what is observed in other parts of the world (Hareide and Garnes, 1998). For this study, a smaller proportion of sets at depths exceeding 500 m were prosecuted for the southern area, 32% in the north, 14% in the south and this may account in part for the fewer records recorded to the south.

An analysis of bottom temperature in relation to depth shows why a more shallow southern sets contained orange roughy. Fig. 7 shows that the 92% of the orange roughy were captured where bottom temperatures exceeded 2.4°C whereas 80% of the study area was associated with bottom temperatures less than this value. However, in three specific areas to the south, namely the Flemish Cap, the southwest slope of the Grand Bank and the Scotian Shelf slope, bottom temperatures are in excess of 4°C at depths less than 500 m. All 18 of the shallow sets (<500 m) containing 22 orange roughy came from these "warm (4-8°C) shallow" areas.

Figure 7 shows a sharp drop in number of roughy caught at 4°C. This is because (with the exception of the 3 "warm shallow areas" specified above) almost none of the area fished (where depth was less than 1600 m) was associated with 4°C+ bottom temperatures. Thus, most warm areas were out beyond the fishing limit of 1600 m. In terms of the availability of suitable habitat for orange roughy in the slope waters off Canada, this leaves the question as to whether orange roughy are found, perhaps in greater abundance at depths exceeding 1600 m on those the slope waters where bottom temperatures are closer to the typical range reported for this species. Hareide and Garnes (1998) reported that the densest concentrations or orange roughy on the mid-Atlantic Ridge were found where bottom temperatures were 7-9°C. At the cold end of the scale, extensive effort directed for Greenland halibut and shrimp north of Lat 65° in deep water between Greenland and Baffin Island yielded no orange roughy. The bottom temperatures in these areas are largely less than 2°C.

Meristics and Morphometrics

Average, range, median mode and variance for measures of body parts and 10 counts are summarized in Table 3. Selected morphometrics and meristics by sex are summarized in Table 4. All of the 27 specimens examined in detail in this study were distinguishable from other Atlantic trachichthyid species by the characteristics listed in Woods and Sonoda (1973) and Merrett and Wheeler (1983). These specimens came from entire the range of the species in the Northwest Atlantic (Fig. 2). Our specimens were also consistent in terms of their meristics with other parts of the world. All counts and measurements fall within the ranges for *H. atlanticus* found by Woods and Sonoda (1973), Paulin (1979) and Kotlyar (1980) in Atlantic, Pacific and Indian Oceans (Table 5).

Two additional trachichthyid species, *Gephyroberyx darwini* and *Hoplostethus mediterraneus* have been captured in the western North Atlantic (Van Guelpen, 1993; Scott and Scott, 1988; Woods and Sonoda, 1973). All fish were examined for the morphological features suggested by Merrett and Wheeler (1983) to differentiate *G. darwini* from *H. atlanticus.* One specimen (295 mm) had a patch of vomerine teeth but corresponded with *H. atlanticus* in all other features. *Hoplostethus atlanticus* can be differentiated from *H. mediterraneus* by its higher dorsal jointed ray count (15-18 *vs.* 10-12) and smaller eye to standard length ratio (7.4-10.1 *vs.* 13.5-16.1).

Standard length (SL) ranged from 295-510 mm. Fish length can be converted from standard length (SL) to fork length (FL) and total length (TL) within this length range by the equations:

$$SL = 0.907\ FL - 2.019 \quad (n = 25;\ r^2 = 0.98)$$
$$SL = 0.813\ TL - 1.935 \quad (n = 18;\ r^2 = 0.98)$$
$$FL = 0.867\ TL + 17.21 \quad (n = 18;\ r^2 = 0.97)$$

where measurements are in mm.

Length-weight relationships, with length in mm and weight (W) in g were calculated as:

$$W = 0.000413\ SL^{2.585} \quad (n = 27;\ r^2 = 0.93)$$
$$W = 0.000189\ FL^{2.671} \quad (n = 25;\ r^2 = 0.95)$$
$$W = 0.000145\ TL^{2.664} \quad (n = 18;\ r^2 = 0.94)$$

The length-weight relationships are similar to those reported from west of Britain (Gordon and Duncan, 1987; unpublished French data cited in ICES 1996) and off Faroe, Iceland and on the Mid Atlantic Ridge (Magnússon and Magnússon, 1995; Thomsen, 1998). A fish measuring 40 cm SL, i.e. about 50 cm TL weighed 2.2 kg in the Northwest Atlantic and 2.0-2.3 kg in the Northeast Atlantic, depending on the regression used. Length conversion factors are also essentially the same as obtained from west of Britain (unpublished French data cited in ICES, 1996) and off Iceland (Magnússon and Magnússon, 1995).

The similarities in orange roughy morphometric and meristic characteristics across its range noted in this and other studies are consistent with the results of genetic studies. Smith (1986) and Elliot *et al*. (1994) indicated similar genetic characteristics between orange roughy from the continental slope off southern Australia, Tasman Sea, South-west Pacific Ocean and North-east Atlantic Ocean. On the other hand, Gauldie and Jones (2000) noted differences in geographically separated populations of the New Zealand orange roughy in relation to parasite infestation, growth rate, and otolith shape, Edmonds *et al*. (1991) discriminated stocks using trace elements from otoliths and Lester *et*

al. 1988 used analysis of parasites to discriminate stocks.

Table 3 and Fig. 8 shows that the total length of orange roughy taken in the present study ranged from 39.5-62.5 (1.14-4.59 kg) with an average of 54.6 cm (2.8 kg). In comparison, the total length of orange roughy taken in the northeast Atlantic (deep-sea banks and pinnacles in the western and southern area in Faroese waters, in the Hatton Bank area and on the Mid-Atlantic Ridge) ranged between 15 and 75 cm, with the majority between 50 and 70 cm (Thomsen 1998). Based on a very small sample, the length distribution was not dissimilar to what was observed in the northeast Atlantic.

Reproduction

Reproductive state was observed for 24 specimens (14 females, 10 males), 19 of which were caught in August to November. Three of the smallest females, 29.5-38.5 cm SL (37-48 cm TL), had ovaries that were translucent and pink in colour, firm and regular in shape and about 30% as wide as long. Two other females in this size range had ovaries that differed only in having walls that were opaque and less pink. In contrast, the nine larger females, 42.0-51.0 cm SL (52-63 cm TL) had ovaries that were relatively larger, purplish and flaccid or, if firm, beige in colour and were, on average, about half as wide as long. Of the males, 41.0-50.0 cm SL (51-62 cm TL), eight had fairly large and firm, cream coloured testes that were about one third as wide as long in two fish of 42.0 and 45.5 cm SL (52 and 56 cm TL) and about half as wide as long in the other six cases. The remaining two had irregular shaped, laterally shrunken testes. Most testes had black spots on their surface, which were extensive in some cases.

It is concluded that all females over 38.5 cm SL were mature but that three, possibly all five, of the females of this size and smaller may have been immature. One female, caught in 4W in July, was clearly at a ripening stage, whereas most of the large females appeared to be spent or recovering, although some of these contained eggs large enough to be seen by the naked eye. All males, with the possible exception of the two fish with the smallest testes, were mature. Several, taken in October-November, appeared to be ripening.

The spawning period in the Northeast Atlantic is in late January to early March (Du Buit, 1995; Thomsen, 1998) and a similar timing could be expected in the Northwest Atlantic. As almost all of the present specimens were collected in August-November, few, if any, instances of the later stages of maturity could be expected in these. The specimens show signs of reproductive development but appear to be mainly in early ripening or spent/recovering stages. However, this does not necessarily mean that development will proceed to spawning. Bell *et al*. (1992) found a high proportion of adult female orange roughy off south-eastern Australia either did not develop or initiated egg production but subsequently resorbed the developing eggs. Specimens collected in the January-March period are required to establish definitively that spawning is occurring in the Northwest Atlantic.

West of Britain, orange roughy have a size at first maturity of about 41 cm SL (51 cm TL) (Du Buit, 1995; Gordon and Duncan, 1987). Thomsen (1998), who sampled more widely, including along the Mid-Atlantic Ridge, found an size at first maturity of about 36 cm SL (44-45 cm TL) and of 50% maturity of 39-40 cm SL (48-49 cm TL). Thus, the interpretation given to present data that some females less than 39 cm SL were likely immature, whereas most if not all larger than this were mature, is consistent with the relationship of maturity to length in the northeast Atlantic.

Food

Of 18 stomachs examine, five were empty. Seven contained creamy or liquefied white or yellow tissue, unrecognizable as to taxon. The remaining six all contained shrimps. These shrimps were recognisable as sergestids in two instances and in a further two as pasiphaeids, in one of which the species was identifiable as *Pasiphaea tarda*. Two stomachs also contained fish, one of which was a 20 cm specimen of the notosudid, *Scopelosaurus lepidus*. One stomach contained two cephalopod beaks. Although few stomachs were examined, these indicate that diet in the northwest Atlantic is similar to that in the Northeast Atlantic (Magnússon and Magnússon, 1995; Mauchline and Gordon, 1984; Thomsen, 1998) and elsewhere (Bulman and Koslow, 1992; Rosecchi *et al*., 1988) in its dependence on benthopelagic decapod crustaceans, fish and cephalopods.

Conclusions

The findings of this study represent a substantial range expansion for orange roughy. Its range in the northwest Atlantic is now defined from southwest Greenland to the Scotian Shelf, a straight-line distance of 2200 km along the North American slope. In closest proximity, it was previously reported southeast of Greenland south along the mid-Atlantic Ridge and on the adjacent Corner Seamounts. The east Greenland concentrations are separated from the northern records for this study by about 1000 km. It seems feasible that the fish west of Greenland (this study) might have a distribution continuous with the eastern Greenland fish but no sampling has been reported for this area south of Greenland. The Corner Seamounts are separated from the Grand Banks directly to the north by about 750 km of very deep waters. No orange roughy have been recorded in US slope waters to the south.

Comparison of relative number of sets with orange roughy in relation to total fishing effort provides some insight with respect to the relationship between northwest Atlantic, mid-Atlantic Ridge and northeast Atlantic orange roughy. To the north, the majority of sets observed, the area with the greatest proportion of sets containing orange roughy and the area with the highest average catch rates were closest in proximity to the northeast Atlantic concentrations to the east between Greenland and Iceland. To the south, orange roughy catch rates were highest along the southwest slope of the Grand Banks closest in the south to the Corner Seamounts.

Available habitat in terms of bottom temperature with respect to depth may explain why orange roughy is scarce along much of the North American slope. On the mid-Atlantic Ridge, it was most highly concentrated where bottom temperatures ranged from 7 to 9°C. Along the North American slope off Canada, bottom waters this warm at least as far south as the slope off the Laurentian Channel cannot be found inside of 3000 m. Thus, the combination of 7-9°C temperatures at depths less than 1600 m (the greatest depths observed in this study) does not exist along the Canadian Atlantic slope. Some of the warmest bottom temperatures inside 1600 m occur between southern Greenland and Baffin Island, the Flemish Cap and the southwest slope of the Grand Bank. It is at those locations that orange roughy were most abundant. As well, the set with the second largest count of orange roughy south of St Pierre Bank (and where the Woods and Sonoda 1973 record is thought to have been) is in closest proximity, about 50 km, to where bottom temperatures exceed 7°C.

Given that morphometric and meristic characteristics and genetics for this species are very similar worldwide (not uncommon for wide ranging, deep dwelling species), including the fish examined in this study, such characteristics cannot be used to examine the relationship between northeast and northwest Atlantic fish. Parasite infestation, growth rate, and otolith shape were used in the Pacific to differentiate populations but that type of information was not available for this area. Gonad work is inconclusive as to whether the northwest Atlantic portion of the population is reproducing locally or are occasional wanderers. Nonetheless, data from 12 years consistently indicates that roughy in the northwest Atlantic are rare but persistently present over time. All of this suggests that northwest Atlantic orange roughy are a western fringe component of the northeast Atlantic population.

Despite its scientific (species) name, orange roughy is not nearly as abundant in the Atlantic as parts of the Pacific Ocean where it has been commercially exploited at numerous locations for more than 20 years. However, following on the development of several smaller fisheries for orange roughy in the northeast Atlantic, the Canadian fishing industry was interested in its potential as a commercial fishery in the northwest Atlantic. The present study conclusively shows that orange roughy while inhabiting a wide area from the southern Davis Strait to the southwest slope of the Scotian Shelf is at best a rare occurrence, probably the fringe of an exploited population far more densely distributed on the mid-Atlantic Ridge, adjacent seamounts and northeast Atlantic slope waters. On the north American slope outside of 1600 m, where the bottom temperatures are more consistent with those where orange roughy congregate in other areas but there are no data, it is possible that higher numbers of orange roughy may exist. However, orange roughy have not been recorded to concentrate at such great depths in other parts of the world.

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Table 1. Total fishing effort observed and records of sets and percent of set with orange roughy by gear in the Northwest Atlantic from fishery observer records, 1991-2000.

Gear	Sets observed	Sets with Orange roughy	% with Orange roughy
All Depths			
Otter trawl	76,801	189	0.2461%
Shrimp trawl	113,004	14	0.0124%
Gillnet	7,938	6	0.0756%
Longline	4,998	0	0.0000%
	202,741	209	0.1031%
Greater than 500 m			
Otter trawl	38,038	186	0.4890%
Shrimp trawl	2,693	1	0.0371%
Gillnet	2,339	6	0.2565%
Longline	2,604	0	0.0000%
	45,674	193	0.4226%

Table 2. Records of sets with orange roughy and counts in the northwest Atlantic by fishery and NAFO Division from observer records, 1991-2000.

Set Count	NAFO Division											
Fishery	**0**	**2G**	**2H**	**2J**	**3K**	**3M**	**3O**	**3Ps**	**4W**	**4X**	**SM**	**Total**
Redfish									1			1
Halibut								1				1
Yellowtail							1					1
Grenadier										3		3
Witch				2			2					4
Alphonsino											7	7
Shrimp	1					13						14
GLHalibut	152	14	8	6	1		1	4				186
All	153	14	8	8	1	13	4	5	1	3	7	217

Percent	NAFO Division											
Fishery	**0**	**2G**	**2H**	**2J**	**3K**	**3M**	**3O**	**3Ps**	**4W**	**4X**	**SM**	**Total**
Redfish									0.5%			0.5%
Halibut								0.5%				0.5%
Yellowtail							0.5%					0.5%
Grenadier										1.4%		1.4%
Witch				0.9%			0.9%					1.8%
Alphonsino											3.2%	3.2%
Shrimp	0.5%					6.0%						
GLHalibut	70.0%	6.5%	3.7%	2.8%	0.5%		0.5%	1.8%				85.7%
All	70.5%	6.5%	3.7%	3.7%	0.5%	6.0%	1.8%	2.3%	0.5%	1.4%	3.2%	

Fish Count	NAFO Division											
Fishery	**0**	**2G**	**2H**	**2J**	**3K**	**3M**	**3O**	**3Ps**	**4W**	**4X**	**SM**	**Total**
Redfish									1			1
Halibut								8				8
Yellowtail							4					4
Grenadier										3		3
Witch				3			2					5
Alphonsino											8	8
Shrimp	1					14						15
GLHalibut	385	27	22	16	5		2	4				461
All	386	27	22	19	5	14	8	12	1	3	8	505

Percent	NAFO Division											
Fishery	**0**	**2G**	**2H**	**2J**	**3K**	**3M**	**3O**	**3Ps**	**4W**	**4X**	**SM**	**Total**
Redfish									0.2%			0.2%
Halibut								1.6%				1.6%
Yellowtail							0.8%					0.8%
Grenadier										0.6%		0.6%
Witch				0.6%			0.4%					1.0%
Alphonsino											1.6%	1.6%
Shrimp	0.2%					2.8%						
GLHalibut	76.2%	5.3%	4.4%	3.2%	1.0%		0.4%	0.8%				91.3%
All	76.4%	5.3%	4.4%	3.8%	1.0%	2.8%	1.6%	2.4%	0.2%	0.6%	1.6%	

# per tow	NAFO Division											
Fishery	**0**	**2G**	**2H**	**2J**	**3K**	**3M**	**3O**	**3Ps**	**4W**	**4X**	**SM**	**Total**
Redfish									1.0			1.0
Halibut								8.0				8.0
Yellowtail							4.0					4.0
Grenadier										1.0		1.0
Witch				1.5			1.0					1.3
Alphonsino											1.1	1.1
Shrimp	1.0					1.1						1.1
GLHalibut	2.5	1.9	2.8	2.7	5.0							2.5
All	2.523	1.929	2.750	2.375	5.000	1.077	2.000	2.400	1.000	1.000	1.143	2.5

Table 3. Summary of morphometric and meristic characteristics of 27 orange roughy from Canadian Atlantic waters. Length measures are in mm and weights in kg. Refer to Woods and Sonoda (1973) and Merrett and Wheeler (1983) for a definition of measures.

Morphometrics

	Stdlen	Forlen	TLup	TLlo	Wt	Bodep	Cadep	Hdlen	Sntlen
Mean	421.4	462.1	519.4	528.9	2668.1	178.4	38.7	147.3	39.6
Stdev	69.3	76.7	84.6	83.0	1046.4	28.5	7.5	22.5	5.5
Min	295	325	375	370	877	130	26	105	28
Max	510	558	620	625	4593	230	55	180	48
Median	440	490	550	553	2835	186	40	152	41
Mode	490	492	550	552	2790	200	40	160	43

	Ordia1	Ordia2	Intorb	Upjaw	Predor	Pecfin	Analen	Caup	Calo	LDorSp
Mean	28.6	37.3	50.2	92.3	191.5	94.6	74.2	93.2	93.2	6.4
Stdev	4.7	5.7	7.2	12.1	29.2	14.4	11.2	39.5	45.1	0.5
Min	19	27	38	69	139	68	50	-55	-56	6
Max	35	44	62	111	225	118	88	123	132	7
Median	30	40	52	97	206.5	96	79	105	110	6
Mode	31	40	38	100	210	73	58	105	110	6

Meristics

	Dorfin	Dorfin1	Dorfin2	Anafin	Anafin1	Anafin2	Pecfin	Pelfin	Pelfin1	Pelfin2	Caufin
Mean	21.9	6.2	15.7	13.9	3.0	10.9	18.6	7.0	1.0	6.0	32.1
Stdev	0.7	0.6	0.5	0.3	0.0	0.3	1.0	0.0	0.0	0.0	1.0
Min	21	6	15	13	3	10	15	7	1	6	30
Max	24	8	16	14	3	11	20	7	1	6	36
Median	22.0	6.0	16.0	14.0	3.0	11.0	19.0	7.0	1.0	6.0	32.0
Mode	22.0	6.0	16.0	14.0	3.0	11.0	19.0	7.0	1.0	6.0	32.0

	Caufin1	Caufin2	Caufin3	Caufin4	Brays	Gilrak	Gilrak1	Gilrak2	Gilrak	Llsca	Abscu	Vert
Mean	6.0	10.1	10.0	6.0	8.0	20.5	6.0	1.0	13.5	30.4	16.7	28.7
Stdev	0.4	0.3	0.2	0.4	0.0	0.9	0.5	0.0	0.9	1.0	1.8	0.5
Min	5	10	10	5	8	18	5	1	12	28	13	28
Max	7	11	11	7	8	22	7	1	15	32	21	29
Median	6.0	10.0	10.0	6.0	8.0	21.0	6.0	1.0	14.0	30.0	17.0	29.0
Mode	6.0	10.0	10.0	6.0	8.0	21.0	6.0	1.0	14.0	30.0	18.0	29.0

Definition of abbreviations

Measures

Stdlen – Standard Length
Forlen – Fork Length
Tlup – Total length upper
Tllo – Total length lower
Wt – Body weight
Bodep – Body depth
Hdlen – Head length
Sntlen – Snout length
Ordia1 – Orbital diameter 1 and 2
Intorb – Interorbital width
Upjaw – Upper jaw length
Predor – Pre-dorsal length
Pecfin – Pectoral fin length (base)
Analen – Anal fin length
Caup – Caudal fin length upper
Calo – Caudal fin length lower
LdorSp – Dorsal spine length

Counts

Dorfin – Dorsal fin (1 & 2) rays
Anafin – Anal fin (1 & 2) rays
Pecfin – Pectoral fin rays
Pelfin – Pelvic fin (1 & 2) rays
Caufin – Caudal (1,2,3) fin rays
Bravs – Brachial rays
Gilrak – Gill raker (1 & 2) count
Llsca – Lateral line scales
Ascu – Scutes in abdominal keel
Vert – Vertebral count

Table 4. Selected orange roughy morphometric statistics by sex.

Sex	Count	Standard Length	Min of Std Length	Max of Std Length	StdDev of Std Length	Count	Fork Length	Min of Fork Length	Max of Fork Length	StdDev of Fork Length
F	13	421.6	295	510	12.0	13	458.1	325	558	92.0
M	10	451.5	410	500	9.0	10	499.9	455	555	33.5
Unsexed	4	345.3	311	385	4.0	4	389.3	342	425	40.1
All	27	421.4	295	510	25.0	27	462.1	325	558	76.7

Sex	Count	Head Length	Min of Head Length	Max of Head Length	StdDev of Head Length	Count	Body Depth	Min of Body Depth	Max of Body Depth	StdDev of Bodep
F	13	147.9	110	180	25.8	13	181	130	230	35.5
M	10	155.7	142	180	10.9	10	187	164	208	11.0
Unsexed	4	124.3	105	150	20.5	4	149	134	164	15.4
All	27	147.3	105	180	22.5	27	178	130	230	28.5

Sex	Count	Snout Length	Min of Snout Length	Max of Snout Length	StdDev of Snout Length	Count	Upper Jaw Len	Min of Upper Jaw Len	Max of Upper Jaw Len	StdDev of Upper Jaw Len
F	13	38.8	28	46	6.1	13	92.3	72	105	13.0
M	10	42.2	38	48	3.4	10	98.5	91	111	5.4
Unsexed	4	34.3	29	38	4.7	4	76.8	69	85	6.8
All	27	39.6	28	48	5.5	27	92.3	69	111	12.1

Table 5. Meristic counts and morphometric measurements for *H. atlanticus* in the present study and comparisons with previous studies. (Morphometric measurements are given as % standard length.)

Measurement	Northwest Atlantic (present study)	Northwest Atlantic (Woods and Sonoda 1973)	Pacific Ocean (Paulin 1979)	Atlantic, Pacific, Indian Ocean (Kotlyar 1980)
Number of fish	27	18	12	25
Standard length range (mm)	295-510	390-492	192-395	86-430
Dorsal fin rays	VI-VII 15-16[1]	V-VI, 15-18	VI 15-18	V-VI 15-18
Anal fin rays	III 10-11	III 10-11	III 10-11	II-III 10-12
Pectoral fin rays	15-20	17-20	18-20	16-20
Pelvic fin rays	I 6	I 6	I 6	I 6
Caudal fin rays	30-36	29-31		
Branchiostegal rays	8	8		
Gill rakers	18-22	20-22	19-21	17-22
Lateral line scales	28-32	29-32	31-34	29-33
Total vertebrae	28-29	29	28	29-30
Scutes in abdominal keel	13-21	13-20	19-25	13-20
Snout length	8.0-10.9	9.1-10.5	8.9-9.8	
Interorbital distance	11.0-13.6	10.9-13.0	11.4-12.9	
Eye orbit diameter	7.4-10.1	8.21-9.56	8.2-9.8	6.5-11.2
Upper jaw length	20.2-25.1	20.1-23.2		
Head length	33.0-37.7[2]	32.5-34.9	33.7-39.1	26.2-39.8
Body depth	38.0-47.5	37.0-44.9	38.5-45.6	32.5-47.6
Pectoral fin length	18.3-26.4	20.7-23.8		
Caudal peduncle depth	7.1-11.4	9.2-11	8.5-10.8	

[1] N=25
[2] N=26

Fig. 1. Map of the Canadian Atlantic showing North and South boxes illustrated in Fig. 2a and b. SS shows the location of the Scotian Shelf insert on Fig. 2b.

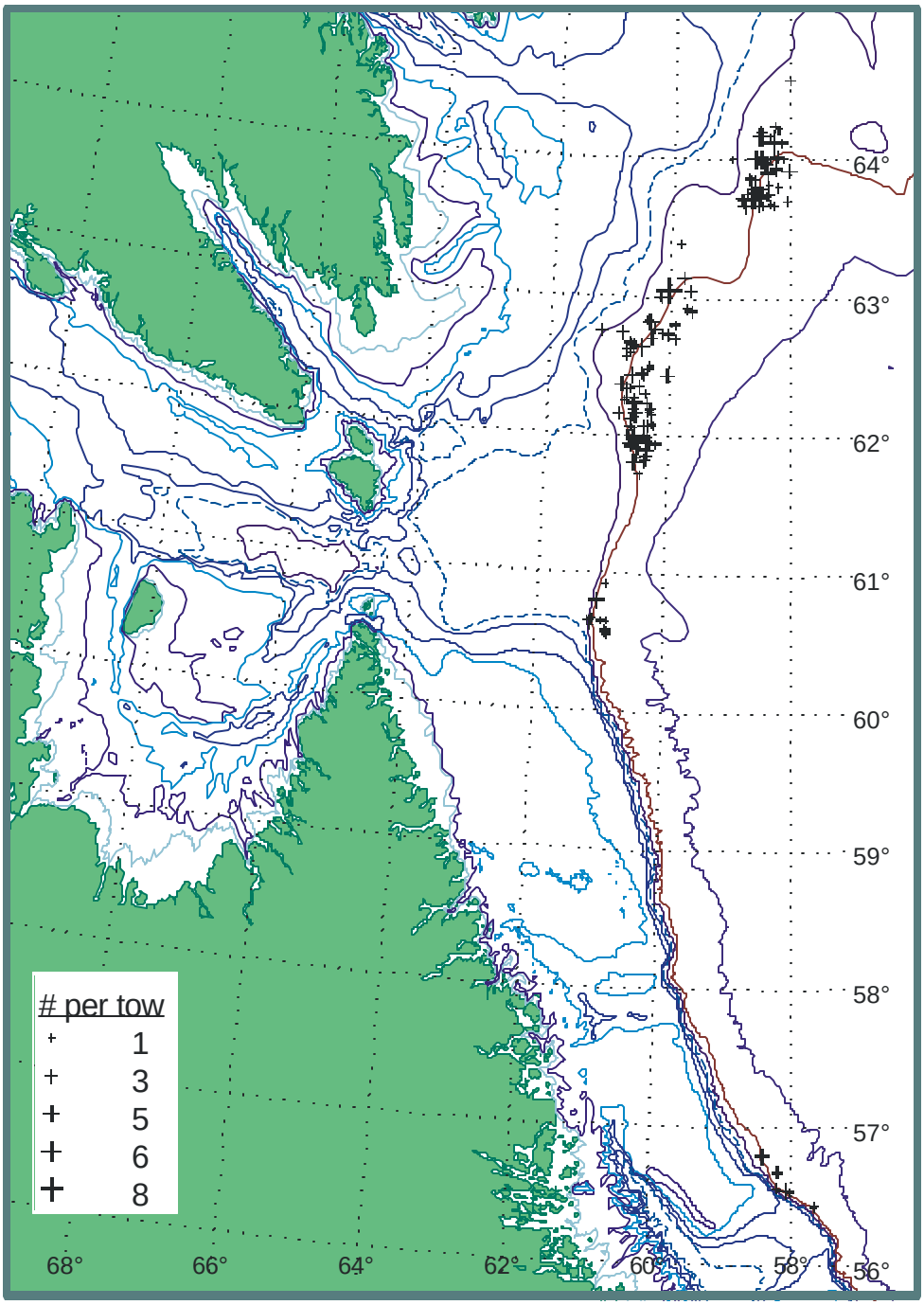

Fig. 2a. Geo-referenced records of orange roughy, northern area (refer to Fig. 1). Variable sized symbols denote numbers caught.

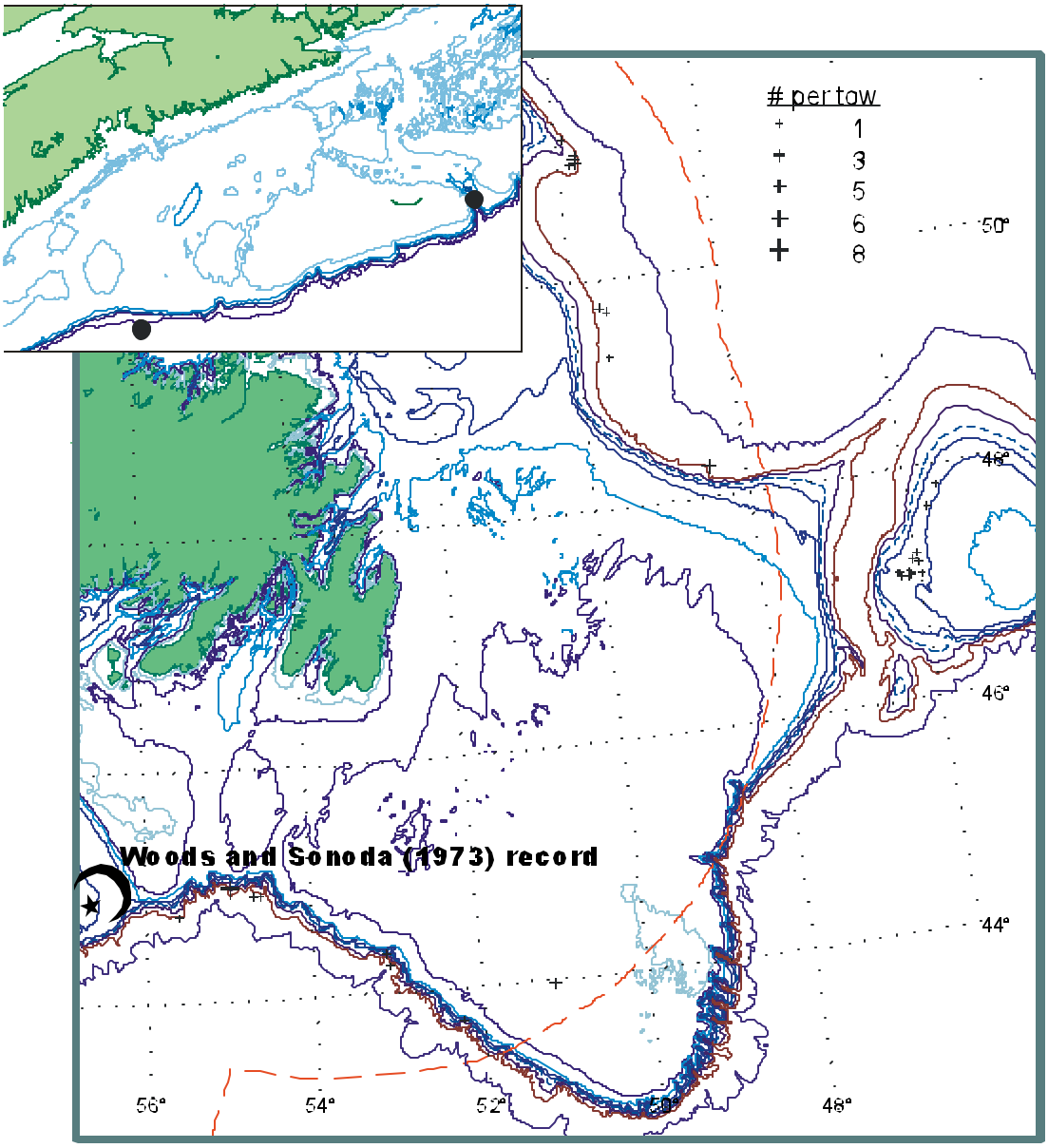

Fig. 2b. Geo-referenced records of orange roughy, southern area (refer to Fig. 1). Variable sized symbols denote numbers caught. The insert (upper left) shows the locaction of the 4 orange roughy sets (1 specimen per set) recorded on the Scotian Shelf as black dots. The western three sets, inclose proximity show as asingle dot.

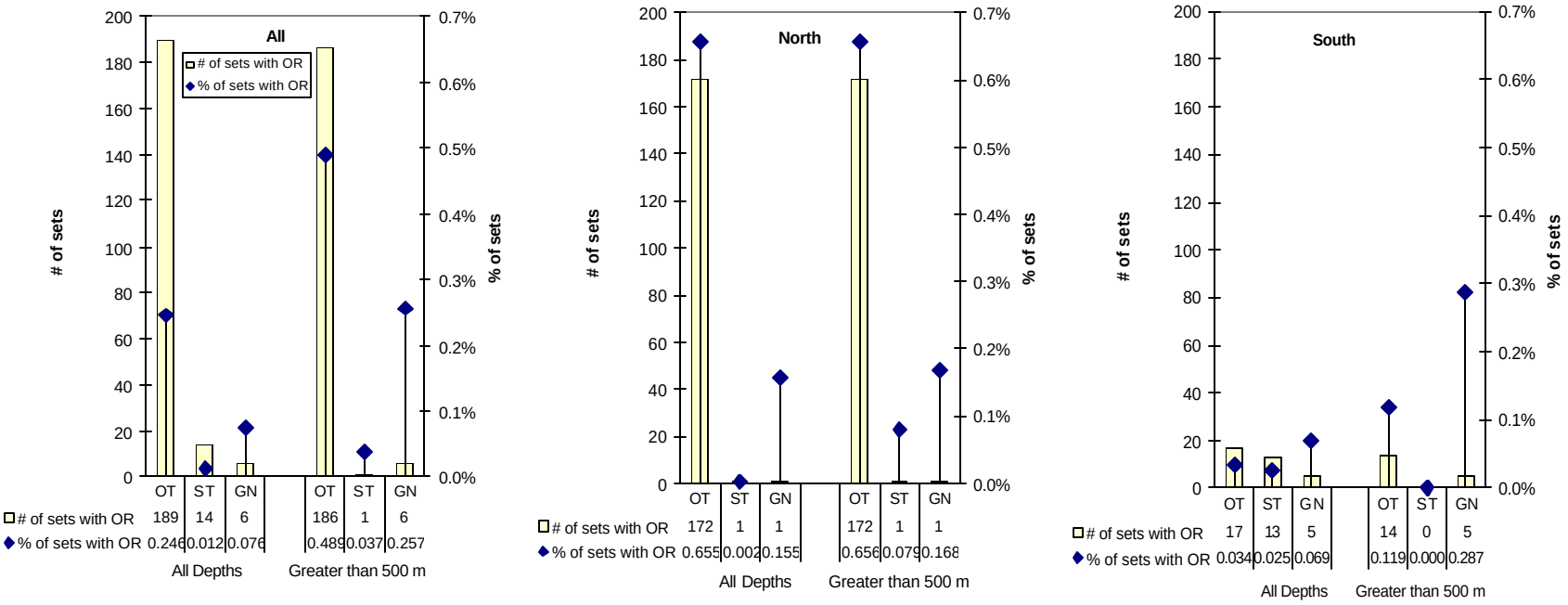

Fig. 3. Occurrence of sets with orange roughy (OR) in relation to total effort observed 1991-2000, all depths and at depths greater than 500 m. The left panel illustrates number and percent of sets with orange over the entire range, the middle panel for north of 55° Lat, the right panel for south of 55° Lat. OT, ST and GN refer to ottere trawl, shrimp trawl and gillnet respectively.

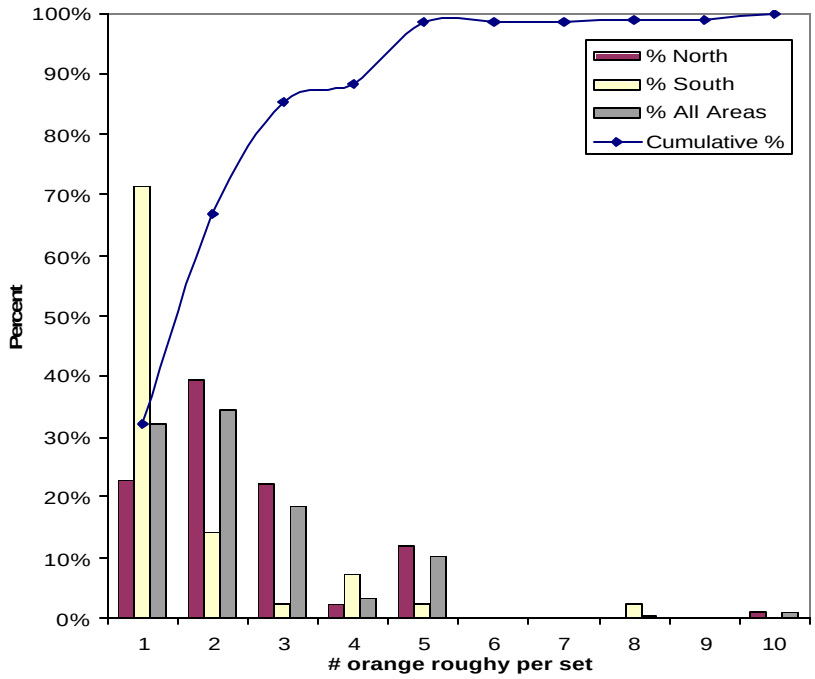

Fig. 4. Frequency of numbers of orange roughy in sets containing orange roughy. North of Lat 55° is differentiated from South of Lat. 55°.

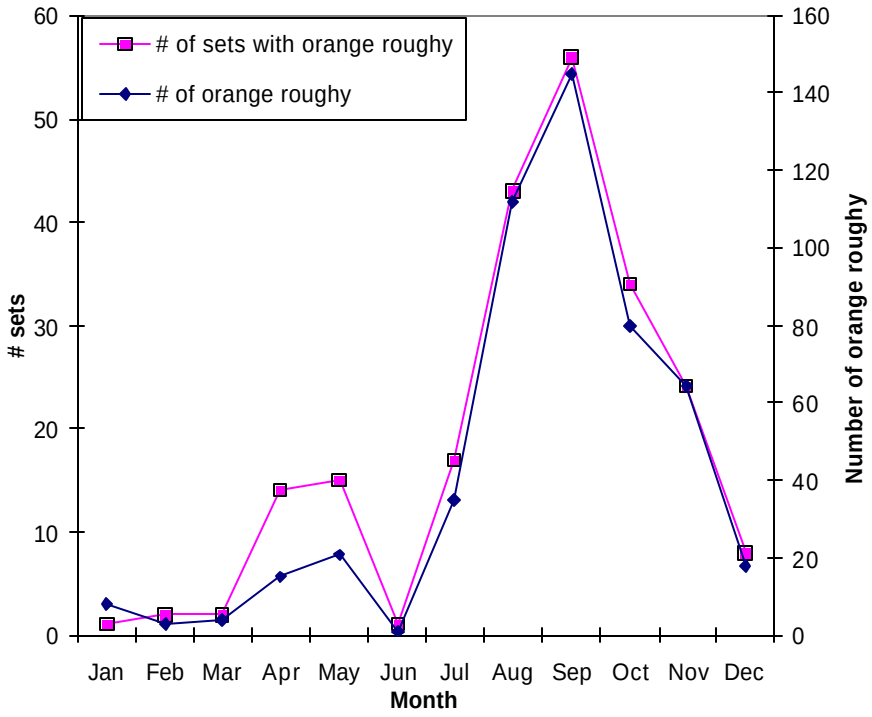

Fig. 5. Number of orange roughy and number of sets with orange roughy by month.

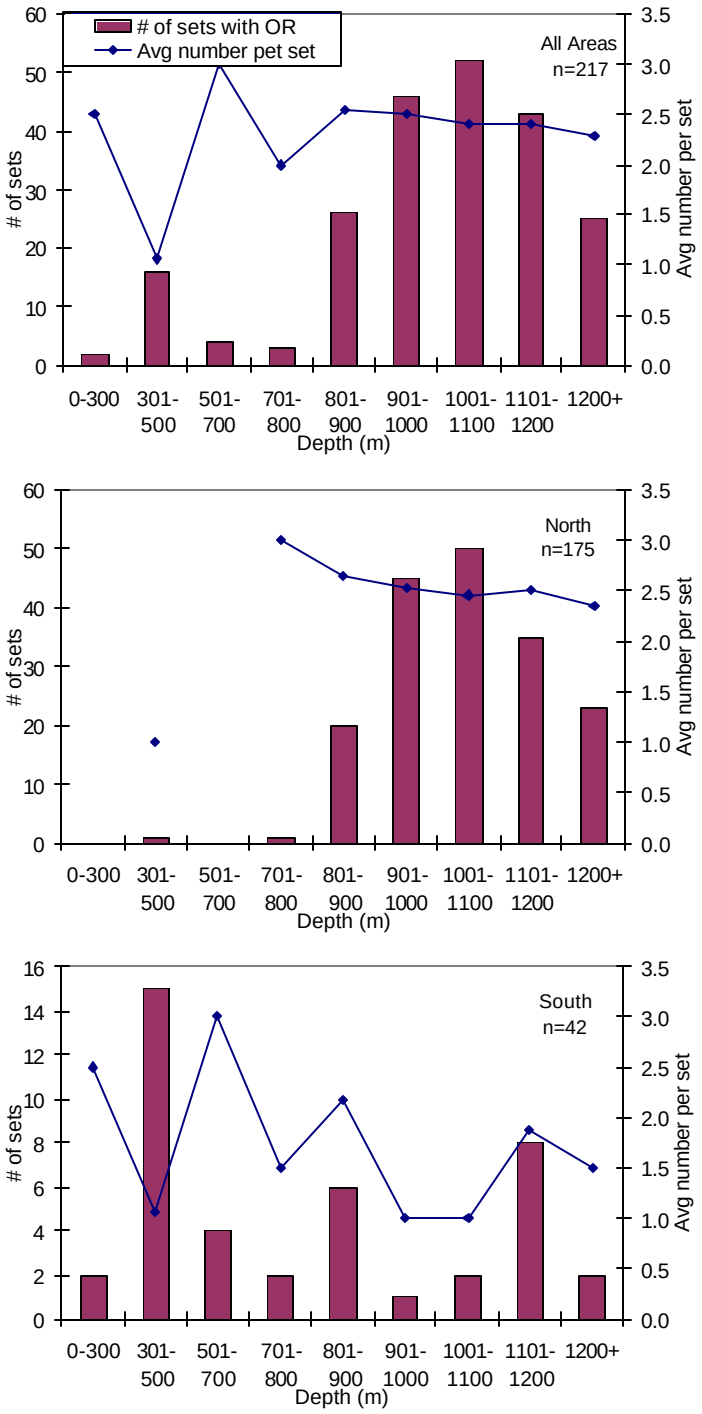

Fig. 6. Orange roughy records from the Canadian Atlantic by depth. Top panel shows count of sets and average number caught per set by depth over the entire range. Middle panel shows the same for the Northern part of the range (refer to Fig. 2), Lower panel the Southern part of the range (refer to Fig. 3).

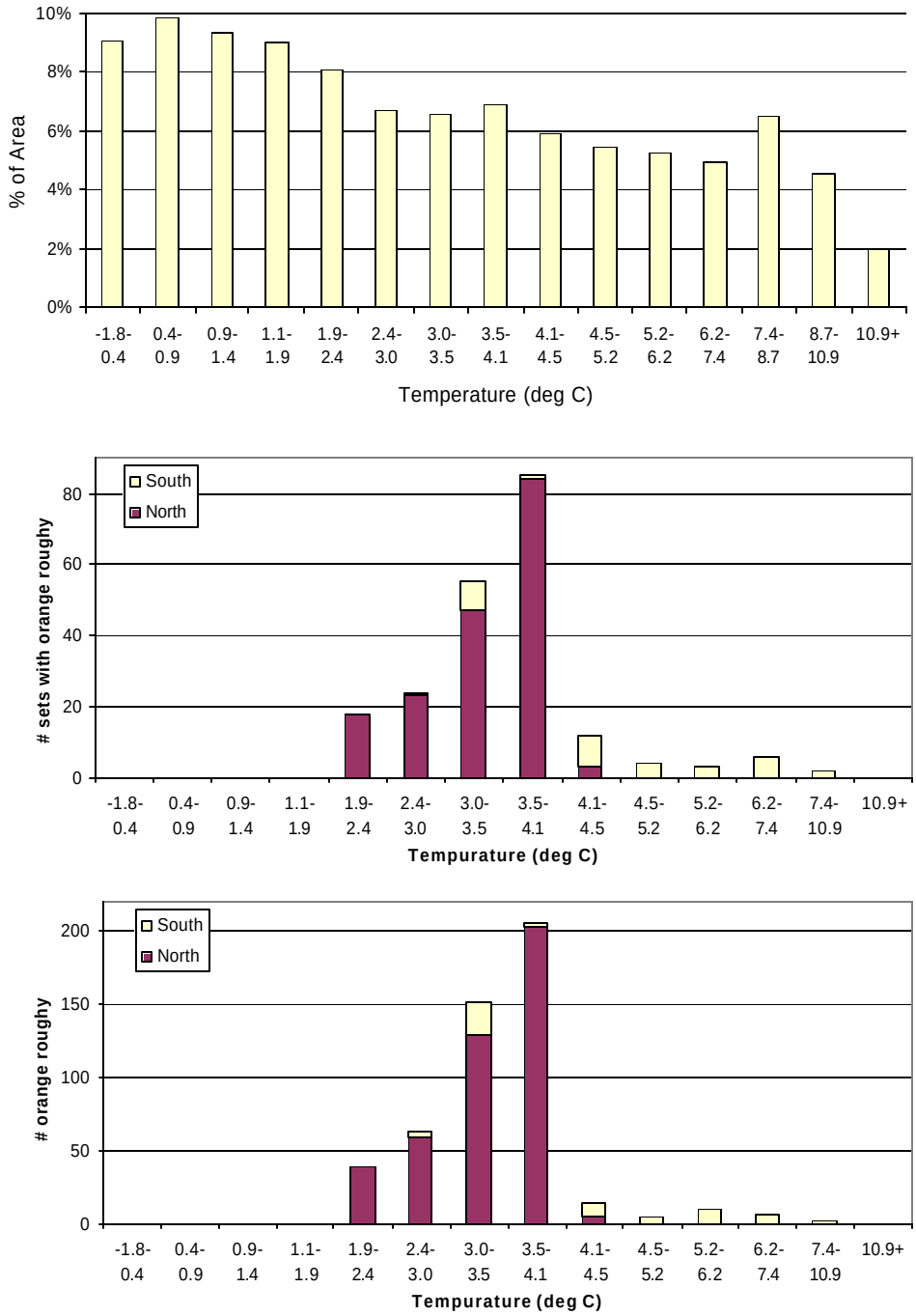

Fig. 7. Available bottom temperature 0-3000 m (upper panel), number of orange roughy sets (middle panel) and number of orange roughy showing sets/number taken within each temperature category. The bottom temperatures are long-term means, 1972-2000.

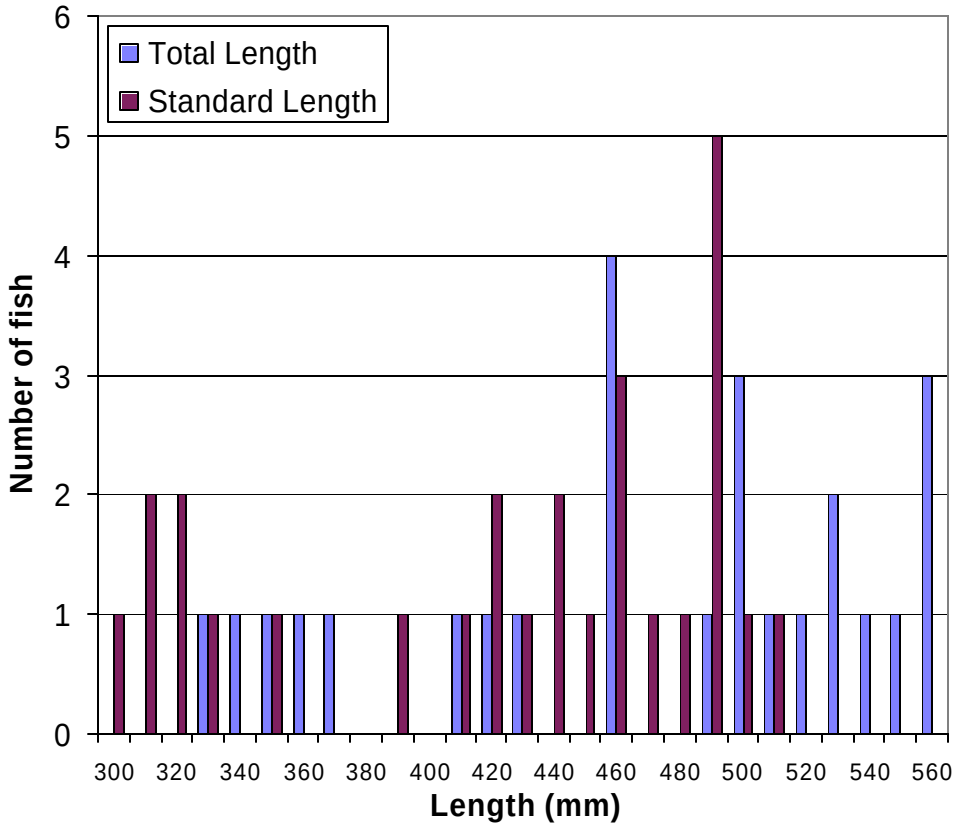

Fig. 8. Length frequency of orange roughy of 27 northwest Atlantic specimens, total length and standard length.

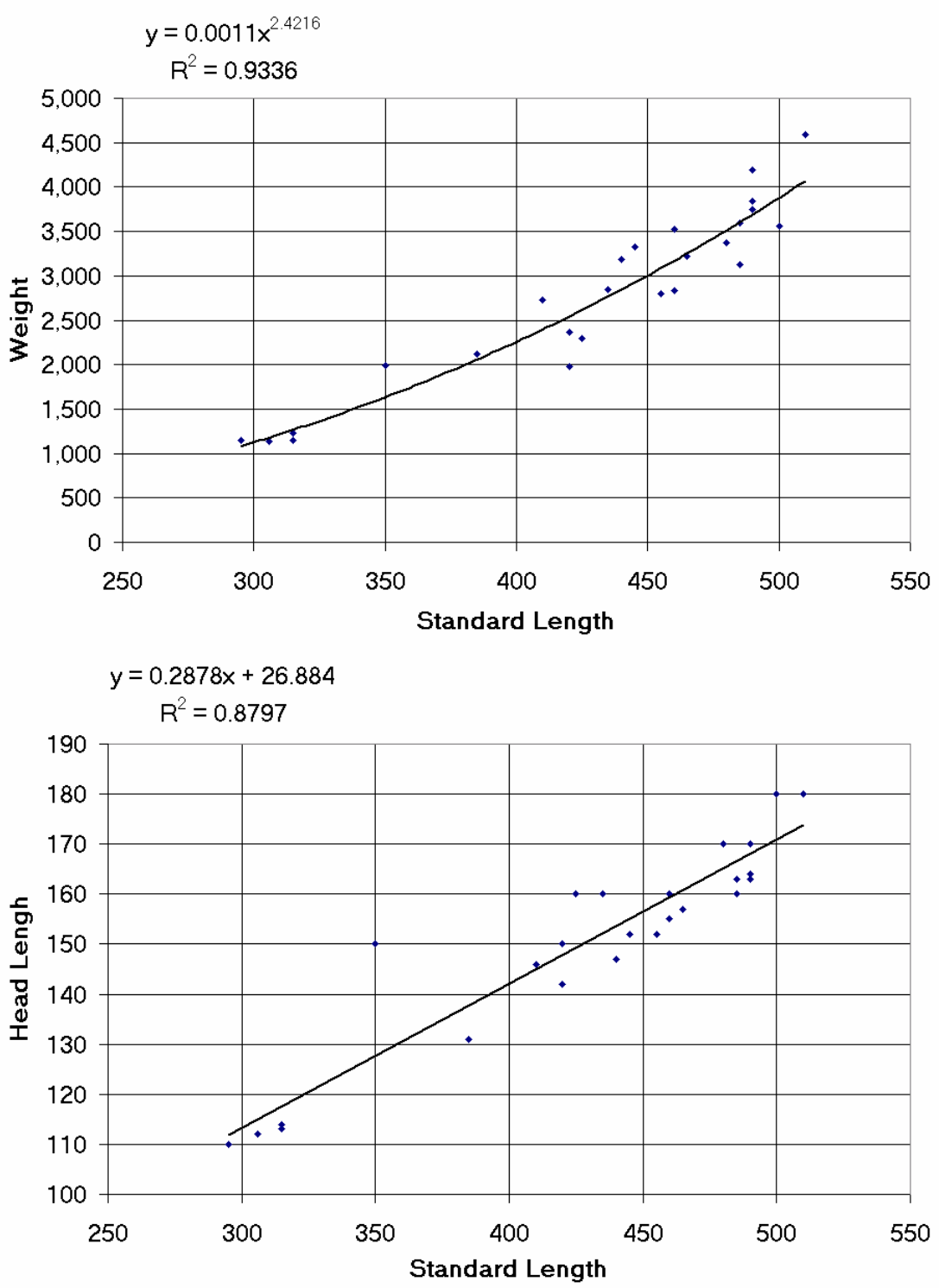

Fig. 9. Relationship between standard length *vs*. head length (upper panel) and standard length *vs*. weight for 25 specimens from Canadian Atlantic waters.