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A Preliminary Analysis of Habitat Use and Movement Patterns of Wolffish (*Anarhichas spp.)* in Coastal Newfoundland Waters

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Determining movement patterns of animals in their natural environment is a difficult task, especially with a number of marine fish species that are distributed over wide geographic areas and often in offshore waters. This paper summarizes initial results of a study conducted in 2010-13 on the distribution and movement patterns of wolffish in coastal waters of the Northeast Avalon Peninsula of Newfoundland (Canada). This research generated acoustic telemetry data, data from direct observations of wolffish during SCUBA surveys to provide a preliminary (qualitative) analysis of habitat use by wolffish in the study area. Wolffish movements varied with geographic scale. Patterns consisted of:

1. remaining in one location (within a 4 km radius) for up to 2 years;
2. remaining in one location for up to a year, and then moving periodically northward and southward along the coastline in spring and summer to another location up to 20 km from the initial location; and
3. long-range movements (> 20 km) beyond the study area.

Overall, the information obtained through the acoustic telemetry, SCUBA surveys, and hydrographic profiling have contributed to a better understanding of life history traits and habitat use by wolffish in Newfoundland coastal waters, especially regarding Atlantic Wolffish.

Analyse préliminaire de l'utilisation de l'habitat et du profil de déplacement du loup de mer (*Anarhichas spp.*) dans les eaux côtières de Terre-Neuve-et-Labrador

RÉSUMÉ

Déterminer le profil de déplacement des animaux dans leur milieu naturel est une tâche difficile, surtout quand bon nombre des espèces de poissons marins sont réparties sur de vastes zones géographiques qui se trouvent souvent dans des eaux de mer ouverte. Le présent document résume les premiers résultats d'une étude menée en 2010-2013 sur la répartition et le profil de déplacement du loup de mer dans les eaux côtières du nord-est de la presqu'île Avalon de Terre-Neuve-et-Labrador (Canada). Cette recherche a généré des données de télémétrie acoustique et des données tirées d'observations directes du loup de mer au cours des relevés en plongée dans le but de fournir une analyse préliminaire (qualitative) de l'utilisation de l'habitat par le loup de mer dans la zone d'étude. Les déplacements du loup de mer ont varié en fonction de l'échelle géographique. Tendances relevées:

1. Le loup de mer reste à un endroit (dans un rayon de 4 km) pour un maximum de deux ans.
2. Le loup de mer reste à un endroit pour un maximum d'un an, puis il se déplace périodiquement vers le nord et vers le sud le long de la ligne de côte au printemps et en été vers un autre endroit situé à un maximum de 20 km de l'endroit initial.
3. Le loup de mer parcourt une grande distance (plus de 20 km) au-delà de la zone d'étude.

Dans l'ensemble, les renseignements obtenus à l'aide de la télémétrie acoustique, des relevés en plongée et des profils hydrographiques ont contribué à une meilleure compréhension des caractéristiques du cycle biologique et de l'utilisation de l'habitat par le loup de mer dans les eaux côtières de Terre-Neuve-et-Labrador, en particulier en ce qui concerne le loup atlantique.

INTRODUCTION

Determining movement patterns of animals in their natural environment is a difficult task, especially with a number of marine fish species that are distributed over wide geographic areas and often in offshore waters. However, understanding how individual fish relate to their habitat both spatially and temporally is crucial to the development of effective habitat and population management policies, such as "critical habitat" for Species at Risk (i.e., a habitat essential for the survival or recovery of a threatened species or population).

Three species of wolffish are found in Canadian Atlantic waters: Northern Wolffish (*Anarhichas denticulatus*), Spotted Wolffish (*A. minor*), and Atlantic Wolffish (*A. lupus*). The first two species were designated as "threatened" after assessment by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), and were listed on Schedule 1 of Canada's *Species at Risk Act* (*SARA*) in 2001, while Atlantic Wolffish was listed as "special concern" (Kulka et al. 2004*a*). The primary reasons for listing these wolffish under *SARA* were: greater than 90 % decline in their abundance indices over 2-3 generations (1980s-90s); and concurrent, substantial reductions in the extent of their distributions.

Although all three species were listed under *SARA* over ten years ago, their movements and behaviours remain relatively unknown, as these species are characterized by broad geographic and depth distributions, tend to be found at low densities, and appear to live a solitary life style except during spawning season (Simpson et al. 2013). This lack of knowledge concerning life history traits (e.g., spatial and temporal aspects of spawning, location of nesting sites, feeding areas) is especially relevant to Northern and Spotted Wolffish, which rarely venture into waters that are sufficiently shallow to permit *in situ* observations using SCUBA. Beyond operational diving depths, there is no information on the movements and reproductive behaviour of wolffish in their natural habitats (Kulka et al. 2004*b*). Based on a tag recapture study, Templeman (1984) suggested that wolffish are mainly sedentary, generally undertaking short movements; although he also noted some rather long migrations.

Few studies have examined live wolffish *in situ* using SCUBA (Keats et al. 1985, 1986; Kulka et al. 2004*b;* Larocque et al. 2008, 2010). These studies have determined that, in nearshore areas, Atlantic Wolffish use natural crevices and narrow spaces between large boulders as "dens" or nesting sites. These shelters appear to play a key role in wolffish life history, because eggs are laid in a cohesive mass by the female wolffish inside the den and are then guarded and aerated by the male (Keats et al. 1985).

The main source of information on fish distribution in the Northwest Atlantic usually consists of large-scale bottom trawl surveys, while remote sensing is typically used to obtain data on fish movement patterns and habitat use. With both methods, these data are collected on a scale of tens of square kilometers, although individual fish interact with its habitat on a scale of tens of meters- thus creating a spatial "disconnect". However, recent advances in acoustic telemetry equipment provide a new method with which data on the movement and distribution of individual marine fish can be obtained.

This paper summarizes initial results of a study conducted in 2010-13 on the distribution and movement patterns of wolffish in coastal waters of the Northeast Avalon Peninsula of Newfoundland (Canada). This research generated acoustic telemetry data, data from direct observations of wolffish during SCUBA surveys, and vertical profiles of water temperature and salinity; then combined these data to provide a preliminary (qualitative) analysis of habitat use by wolffish in the study area.

MATERIALS AND METHODS

The study area consisted of coastal waters of the Northeast Avalon Peninsula on the island of Newfoundland, Canada (Fig. 1), in which acoustic telemetry, hydrography, and *in situ* observations with SCUBA were conducted in 2011-2013. Wolffish were captured as bycatch in the commercial lobster fishery occurring in Conception Bay (adjacent to the Northeast Avalon Peninsula), in targeted fishing off of Torbay, and in Fisheries and Oceans Canada-NL Region (DFO-NL) bottom trawl surveys conducted in offshore areas.

For acoustic telemetry, most wolffish specimens (70 %) were captured as bycatch in the commercial lobster fishery, while 3 % and 27 % were obtained during DFO-NL research surveys with modified crab pots (inshore) and bottom trawls (offshore), respectively (Table 1). Wolffish from those sources were manually removed from fishing gear and placed in a portable aerated seawater tank. Each fish was sedated with tricaine methanesulfonate powder (TMS, MS-222) dissolved in seawater (< 0.2 g/L). Once anesthetized, each specimen was measured for weight (g) and total length (cm), and then a 1.5 to 3 cm incision was cut in the outer skin at 6-12 cm anterior to the anus. A 1.5 cm incision was then made in the belly muscle while avoiding damaging internal organs. An acoustic transmitter (VEMCO V13 or V16) was then implanted in the specimen's abdominal cavity, and 2-3 stiches were used to close both the inner and outer incisions. Once activated, each acoustic transmitter ping continuously at a specific operating frequency (i.e. each transmitter has a unique 'acoustic signature'), thus allowing the tracking of each individual fish by the moored hydrophone arrays. A "Floy" tag was also attached externally at the base of the dorsal fin. Following recovery from sedation in the aerated water tank, each wolffish was released at the location of capture.

In total 25 VEMCO VR2W hydrophone receivers were moored throughout the study area (21 hydrophones in Conception Bay, 1 in Pouch Cove, 1 in Torbay, and 2 Petty Harbour) to detect the presence and movement of tagged wolffish (Table 2). Each hydrophone was mounted on a rope 1 m above a 23 kg cast iron anchor, with a float attached 1 m above the hydrophone. Distance between hydrophones ranged from 1 to 3 km, and from 8 to 15 km on the eastern and western shores of Conception Bay, respectively, and between 13 and 40 km on the northeast shore of the Avalon Peninsula (from Pouch Cove to Petty Harbour). Each moored hydrophone has a detection radius of approximately 4 km, and any wolffish implanted with a transmitter found in this zone would have its unique operating frequency registered by the hydrophone for as long as it remained within the detection zone. Additional monitoring of tagged wolffish location was conducted with a portable VR100 acoustic receiver. During these coastal surveys aboard a small vessel in 2011, vertical profiles of water temperature and salinity were obtained with a SEABIRD Conductivity-Temperature-Depth profiler.

SCUBA was used to visit locations and observe wolffish *in situ*. These surveys covered burrowing areas and crevices under large boulders, and rocky or reef-like structures near shore at operational diving depths. Data recorded by divers included number of wolffish found at such locations (e.g., a nest-guarding male; a male and female spawning pair), presence of dens and wolffish egg masses, presence of wolffish prey and other species at each location, surface and seafloor temperatures, and den depth and position (latitude, longitude). SCUBA surveys were only conducted during daylight hours.

RESULTS

TELEMETRY

Forty-four Atlantic Wolffish and 5 Spotted Wolffish were tagged and released in Conception Bay (adjacent to the NEA Peninsula; Table 2). Of these, 39 Atlantic Wolffish and 1 Spotted Wolffish were detected in Conception Bay between May 2011 and June 2013 by either moored hydrophones or a portable acoustic receiver (VR100). In addition, 2 specimens (1 Atlantic Wolffish and 1 Spotted Wolffish) were detected in the Baccalieu Island area (between Conception Bay and Trinity Bay), and 3 others (2 Atlantic Wolffish and 1 Spotted Wolffish) were detected off of Petty Harbour (NEA Peninsula; Fig. 2). Two Atlantic Wolffish were tagged and released in coastal waters off of Torbay in 2011, and another 19 fish (12 Atlantic Wolffish, 5 Spotted Wolffish, 2 Northern Wolffish) were opportunistically tagged and released offshore (NAFO Div. 3KL) during the DFO-NL 2012 fall bottom trawl survey. None of these "offshore" fish have been detected or recaptured to date. The Wolffish tagged in Torbay were detected in subsequent coastal surveys (2011, 2012) with the VR100 at the same locations where they were released, suggesting that the individuals died shortly after being tagged. The number of days between the first and last detections ranged from 1 to 478, and tagged wolffish were detected continuously from 7 to 177 days in 82% of observations. Detections of only three days or less were observed for 8 wolffish (Table 3). The latter does not include the two wolffish detected in Torbay.

Wolffish movements varied with geographic scale (Fig. 3-5). Patterns consisted of:

1. remaining in one location (within a 4 km radius) in Conception Bay for up to 2 years;
2. remaining in one location for up to a year, and then moving periodically northward and southward along the Conception Bay coastline in spring and summer to another location up to 20 km from the initial location; and,
3. long-range movements (> 20 km) beyond the study area.

The most common pattern (71 %) consisted of wolffish being detected at a single location throughout the time series (pattern #1), followed by wolffish displaying an intermediate-range of movements (18 %; pattern # 2) in Conception Bay. Only 5 wolffish (11 %) exhibited long-range movements beyond the study area (pattern # 3). Furthermore, wolffish that exhibited mid- to long-range movements (including 2 Spotted Wolffish) were of intermediate to large sizes (60-86 cm). Sedentary behavior was observed among wolffish of all sizes, including the smallest (< 50 cm) and largest (> 86 cm) tagged specimens (Fig. 6).

These patterns also showed considerable variation in wolffish behavior. In 67 % of observations, wolffish were active throughout the day (i.e., they were found in open water and detected continuously around the clock by hydrophones). Alternatively, activity was reduced to only a few hours per day, and most frequently around sunrise and sunset (Fig. 7). The first temporal pattern was typically observed in spring and summer, and the latter found during fall and winter.

HYDROGRAPHY

Water temperature and salinity profiles to depths of 120 m were obtained from June 29 to September 19, 2011 (Fig. 8). Water temperature varied between 3.3˚C (June) and 3.9˚C (September) at the surface, and 2.7^{o}C at maximum depth. Thermocline depth ranged from 9 to 22 m, and was deepest in September. Salinity varied between 31.2 ppm at the surface and 32.9 ppm (August) at maximum depth, and changed with month. Pycnocline depth was shallowest (10 m) in August and deepest (32 m) in September.

SCUBA SURVEYS

Forty-two SCUBA surveys were conducted in the study area in spring, summer, and fall in 2009-2013 (Table 4). Most surveys occurred in waters adjacent to Bauline (34), followed by Torbay (10), and Flatrock (2). Survey length varied from 15 to 49 minutes, while survey depth was between 5 and 23 m. Water temperature measured during dives ranged between 0 and 20˚C at the surface, and -0.6 and 15.8˚C at survey depth, and were much wider than the temperature ranges obtained using vertical CTD profilers in 2011. The sea floor surveyed was typically rocky: characterized by large boulders and steep slopes (Fig. 9).

Twenty-five Atlantic Wolffish were observed by SCUBA divers in 14 out of 42 surveys, during which 8 wolffish were observed in open water, and 17 were found inside dens (either in a mating pair or alone). During one survey, an egg mass was observed anchored inside a den and being guarded by one of the parents (Fig. 10). Wolffish were observed in open water over June-August when water temperature near the sea floor was cooler (4.4-10˚C); whereas individuals were found in dens between July and October in warmer water (7.8-15˚C). Invertebrate prey (e.g., shellfish, sea urchins) and other fish species were observed in 6 SCUBA surveys in the water column and near wolffish dens when wolffish were present (Fig. 11).

DISCUSSION

Despite the short time series (2011-13), acoustic telemetry proved to be a suitable method for studying wolffish behavior, distribution, and movement patterns in coastal waters. Most wolffish tagged and released in Conception Bay were subsequently detected (63 %) by a network of moored hydrophones and a portable acoustic receiver on board a small vessel. Furthermore, less than 37 % mortality of wolffish resulted from the capture, handling, and abdominal surgery performed on specimens for acoustic tag insertion.

Data from SCUBA surveys were in good agreement with wolffish distribution and movements patterns inferred from telemetry data. These *in situ* surveys also provided information on wolffish behavior, habitat use, and prey associations. Notably, the identification of dens occupied by Atlantic Wolffish pairs or solitary males, and especially the discovery of an egg mass being guarded by a male parent occupying a den in 2011, confirmed habitat required for spawning by this species along the eastern coastline of Conception Bay. These habitats were found at depths < 20 m (i.e., above the thermocline and in the warmest waters) and were characterized by a rocky sea floor, with large boulders, natural fissures and crevices along steep slopes. The latter is based of observations recorded within dive depth (5-23 m), and does not exclude the possibility that dens could also be present in deeper water. In addition, SCUBA surveys found shellfish and sea urchin debris accumulated near entrances to Atlantic Wolffish dens, thereby indicating that Atlantic Wolffish feed at these shallow coastal habitats.

Atlantic Wolffish were observed in the study area in all seasons and typically displayed reduced mobility: 71 % of specimens detected acoustically remained in one or two locations throughout the study period. However, 18 % of tagged individuals moved regularly for short to intermediate-range distances, and 11% (including two Spotted Wolffish) moved away from the study area covering distances > 20 km. These patterns are similar to those inferred for wolffish living in offshore areas (Templeman 1984).

Wolffish movements varied according to season. Wolffish were frequently found in open water during both daylight and nighttime. This behavior was prevalent in spring and summer and corroborates the findings described by Kulka et al. (2004b). In fall and winter, wolffish were active during a few hours of the day, often at dawn and dusk. The spring and summer pattern is possibly related to water temperature increases due to longer solar irradiation and an influx of warmer offshore water masses into Conception Bay (DeYoung and Sanderson 1995). The latter pattern is also probably coupled to increased availability of prey and forage species, as evidenced by commercial fisheries (e.g., Snow Crab, American Lobster) and other species' life history events (e.g., Capelin beach spawning, Mackerel and Atlantic Herring feeding grounds), occurring in Conception Bay during this season (Nakashima and Slaney 1993). In contrast, Atlantic Wolffish activities in fall and winter seem to follow a diel cycle, suggesting a feeding coupling with the vertical movement of particular prey and forage species through the water column at sunrise and sunset.

Spatial variation in movement relative to wolffish size was also observed. Tagged specimens of intermediate to large sizes were found to swim distances > 20 km, while shorter range movements (4-20 km) were limited to wolffish of small to intermediate sizes. Nottestad et al. (1999) suggested that migration distance for various fish species in the Northeast Atlantic Ocean is a function of body length, and that long-distance migration costs may exceed energy intake for smaller fish. A similar strategy may also apply to wolffish.

In summary, information obtained through acoustic telemetry, SCUBA surveys, and hydrographic profiling contributed to a better understanding of life history traits and habitat use by wolffish in Newfoundland coastal waters, especially regarding Atlantic Wolffish. This study (1) confirmed the existence of wolffish spawning sites and feeding grounds, and possibly nursery areas in nearshore waters; (2) identified habitat features that are probably key to nest site selection by wolffish (i.e., steep slope and rocky sea floor with crevices and large boulders in shallow and warmer waters; availability of prey species near dens); (3) increased knowledge on wolffish behavior, distribution, and movement patterns (i.e., mostly sedentary behavior; movements dependent on season and wolffish size); and (4) showed that handling survival of tagged wolffish was high-at least 63 % of tagged specimens were still alive after a 1 to 2-year period.

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TABLES

Table 1. Capture summary from the wolffish tagging and telemetry study in coastal waters of the Northeast Avalon Peninsula (NF; 2011-2013). Species: Northern Wolffish (699), Atlantic Wolffish (700), Spotted Wolffish (701). Gear: commercial lobster trap (CL), research crab pot (RP), research bottom trawl (RT). Latitude and longitude are the both the location of capture and release.

Species	Acoustic Tag #	Release Date	Capture Method	Location	NAFO	Latitude (Dec. Deg.)	Longitude (Dec. Deg.)	Total Length (cm)	Weight (kg)
700	60776	14-12-2011	CL	Conception Bay	3L	47.7203	-52.8344	86	4.2
700	60774	14-12-2011	CL	Conception Bay	3L	47.7203	-52.8344	78	3.6
701	60775	14-12-2011	CL	Conception Bay	3L	47.7203	-52.8344	76	4.2
701	60777	21-04-2011	CL	Conception Bay	3L	47.7203	-52.8344	61	2.3
700	60778	21-04-2011	CL	Conception Bay	3L	47.7203	-52.8344	62	1.9
701	60779	21-04-2011	CL	Conception Bay	3L	47.7202	-52.8344	70	3.7
701	60780	21-04-2011	CL	Conception Bay	3L	47.7203	-52.8344	65	3.0
701	60781	21-04-2011	CL	Conception Bay	3L	47.7203	-52.8344	86	7.6
700	60783	27-04-2011	CL	Conception Bay	3L	47.7136	-52.8413	62	2.6
700	60782	30-05-2011	CL	Conception Bay	3L	47.7260	-52.8346	75	3.1
700	41647	21-06-2011	CL	Conception Bay	3L	47.6958	-52.8498	90	5.2
700	41648	21-06-2011	CL	Conception Bay	3L	47.6958	-52.8498	71	3.9
700	41649	21-06-2011	CL	Conception Bay	3L	47.6958	-52.8498	74	4.6
700	41654	21-06-2011	CL	Conception Bay	3L	47.7151	-52.8421	62	2.3
700	41650	21-06-2011	CL	Conception Bay	3L	47.7136	-52.8413	71	3.1
700	41651	21-06-2011	CL	Conception Bay	3L	47.7240	-52.8349	67	2.3
700	41652	21-06-2011	CL	Conception Bay	3L	47.7240	-52.8349	63	2.3
700	41653	22-06-2011	CL	Conception Bay	3L	47.7881	-52.8139	70	3.3
700	41656	22-06-2011	CL	Conception Bay	3L	47.7881	-52.8139	64	2.4
700	41655	22-06-2011	CL	Conception Bay	3L	47.7200	-52.8387	72	3.0
700	41657	28-06-2011	RP	Torbay	3L	47.6750	-52.7178	67	2.6
700	41659	28-06-2011	RP	Torbay	3L	47.6750	-52.7178	78	4.3
700	41658	06-07-2011	CL	Conception Bay	3L	47.7173	-52.8394	70	3.3
700	41660	06-07-2011	CL	Conception Bay	3L	47.7084	-52.8446	68	2.4
700	41661	06-07-2011	CL	Conception Bay	3L	47.7084	-52.8446	73	2.8
700	41662	07-07-2011	CL	Conception Bay	3L	47.7011	-52.8508	83	NA
700	41663	20-07-2011	CL	Conception Bay	3L	47.7314	-52.8308	82	NA
700	41667	20-07-2011	CL	Conception Bay	3L	47.7314	-52.8308	81	NA
700	41665	13-09-2011	CL	Conception Bay	3L	47.7696	-52.8181	69	3.2

Species	Acoustic Tag #	Release Date	Capture Method	Location	NAFO	Latitude (Dec. Deg.)	Longitude (Dec. Deg.)	Total Length (cm)	Weight (kg)
700	41669	15-05-2012	CL	Conception Bay	3L	47.7881	-52.8139	62	1.8
700	41666	17-05-2012	CL	Conception Bay	3L	47.7163	-52.8402	60	1.9
700	41664	22-05-2012	CL	Conception Bay	3L	47.7511	-52.8243	62	1.9
700	29263	22-05-2012	CL	Conception Bay	3L	47.7511	-52.8243	68	2.8
700	29265	22-05-2012	CL	Conception Bay	3L	47.7511	-52.8243	67	2.9
700	29270	22-05-2012	CL	Conception Bay	3L	47.7511	-52.8243	72	2.9
700	29258	22-05-2012	CL	Conception Bay	3L	47.7511	-52.8243	69	2.8
700	29262	22-05-2012	CL	Conception Bay	3L	47.7511	-52.8243	70	3.3
700	29267	28-05-2012	CL	Conception Bay	3L	47.7250	-52.8340	76	3.5
700	29259	28-05-2012	CL	Conception Bay	3L	47.7250	-52.8340	61	1.8
700	29257	05-06-2012	CL	Conception Bay	3L	47.7250	-52.8340	78	3.7
700	29256	05-06-2012	CL	Conception Bay	3L	47.7163	-52.8402	68	2.6
700	29260	05-06-2012	CL	Conception Bay	3L	47.7163	-52.8402	55	1.4
700	29264	18-06-2012	CL	Conception Bay	3L	47.7163	-52.8402	86	5.3
700	29266	19-07-2012	CL	Conception Bay	3L	47.7250	-52.8340	69	2.9
700	41677	03-12-2012	RT	Shelf	3K	49.7598	-51.6108	49	1.0
700	41678	03-12-2012	RT	Shelf	3K	49.8032	-51.5018	48	0.9
700	41679	03-12-2012	RT	Shelf	3K	49.7100	-51.4633	56	1.4
700	41675	03-12-2012	RT	Shelf	3K	49.7100	-51.4633	47	0.9
700	41674	02-12-2012	RT	Shelf	3K	49.7100	-51.4633	73	3.4
700	41676	02-12-2012	RT	Shelf	3K	49.6668	-51.3337	45	0.7
700	41673	02-12-2012	RT	Shelf	3K	49.6668	-51.3337	52	1.5
700	41672	02-12-2012	RT	Shelf	3K	49.6668	-51.3337	51	1.3
701	41671	02-12-2012	RT	Grand Bank	3L	49.5235	-51.1817	74	4.3
701	41683	10-12-2012	RT	Grand Bank	3L	50.9883	-51.1500	78	3.9
700	41685	10-12-2012	RT	Grand Bank	3L	50.9883	-51.1500	52	1.3
701	41686	10-12-2012	RT	Grand Bank	3L	50.9883	-51.1500	65	2.7
700	41687	10-12-2012	RT	Grand Bank	3L	50.9883	-51.1500	56	1.6
700	41689	10-12-2012	RT	Grand Bank	3L	50.9883	-51.1500	51	1.2
701	41682	10-12-2012	RT	Grand Bank	3L	50.8650	-51.2050	97	9.9
700	41688	10-12-2012	RT	Grand Bank	3L	50.7933	-51.2600	58	1.7
699	41680	10-12-2012	RT	Grand Bank	3L	50.5667	-51.6367	78	5.1
701	41681	10-12-2012	RT	Grand Bank	3L	50.5667	-51.6367	75	4.3
699	41684	10-12-2012	RT	Grand Bank	3L	50.6517	-52.1883	75	4.4
700	41690	16-05-2013	CL	Conception Bay	3L	47.7187	-52.8393	61	1.7

Species	Acoustic Tag #	Release Date	Capture Method	Location	NAFO	Latitude (Dec. Deg.)	Longitude (Dec. Deg.)	Total Length (cm)	Weight (kg)
700	41691	05-06-2013	CL	Conception Bay	3L	47.7431	-52.8245	71	2.95
700	41692	05-06-2013	CL	Conception Bay	3L	47.7431	-52.8245	68	2.9
700	41693	19-06-2013	CL	Conception Bay	3L	47.7227	-52.8343	70	2.85
700	41694	21-06-2013	CL	Conception Bay	3L	47.7227	-52.8343	75	3.7
700	41695	22-07-2013	CL	Conception Bay	3L	47.7227	-52.8343	76	2.75

Table 2. Position of moored hydrophones deployed in Conception Bay and the Northeast Avalon Peninsula.

Hydrophone No.	Latitude (N)	Longitude (W)
VR2W-102508	47.7553	52.8222
VR2W-102514	47.7001	52.8536
VR2W-109283	47.6551	52.8562
VR2W-100397	47.5937	52.8959
VR2W-109529	47.6311	52.8595
VR2W-114464	47.6235	53.0197
VR2W-114466	47.5674	52.9140
VR2W-114467	47.7182	52.8423
VR2W-114468	47.6951	52.8525
VR2W-114470	47.6311	52.8607
VR2W-114471	47.7302	52.8342
VR2W-114472	47.7001	52.8536
VR2W-114473	47.6790	52.8536
VR2W-119541	47.7560	52.8235
VR2W-119542	47.6107	52.8829
VR2W-119543	47.7841	52.8171
VR2W-108447	48.1647	52.8249
VR2W-108454	48.0966	52.8359
VR2W-108457	48.1012	52.8229
VR2W-122191	47.7693	52.8196
VR2W-122190	47.7456	52.8271
VR2W-122189	47.9904	52.9747
VR2W-122188	47.8819	53.0514
VR2W-122192	47.6591	52.6545
VR2W-114465	47.7607	52.0709

Table 3. Wolffish acoustic detection data from hydrophone stations in the study area.

Acoustic Tag #	First Detection	Last Detection	# Days Between First and Last Detection	# Days with Detections
60783	27-05-2011	31-05-2012	364	37
60782	30-05-2011	31-05-2012	360	129
41650	22-06-2011	13-09-2011	81	32
41652	22-06-2011	28-05-2012	336	4
41653	22-06-2011	22-06-2011	1	1
41656	22-06-2011	25-06-2012	363	23
41648	29-06-2011	22-05-2012	323	10
41657	19-07-2011	01-05-2012	282	7
41659	19-07-2011	09-09-2011	50	6
41663	20-07-2011	22-05-2012	302	32
41667	20-07-2011	12-02-2012	202	68
41649	25-07-2011	22-05-2012	297	4
41651	25-07-2011	14-08-2011	19	11
41655	25-07-2011	23-11-2012	478	52
41658	25-07-2011	31-08-2011	36	3
41660	25-07-2011	12-07-2012	347	116
41661	25-07-2011	06-06-2012	311	116
60776	25-07-2011	11-10-2011	76	17
41662	26-07-2011	25-06-2012	329	39
41666	28-07-2011	26-05-2012	298	4
41654	29-07-2011	24-06-2012	325	6
41647	10-08-2011	22-08-2011	12	2
41665	22-08-2011	20-09-2011	28	9
60779	14-11-2011	20-12-2011	36	5
60778	21-11-2011	21-11-2011	1	1
60777	30-11-2011	01-12-2011	2	2
41669	15-05-2012	10-10-2012	145	88
29258	22-05-2012	19-05-2013	357	6
41664	22-05-2012	22-05-2012	1	1
29270	27-05-2012	08-06-2013	371	56
29256	12-06-2012	13-06-2013	361	167
29257	18-06-2012	18-06-2012	1	1
29264	18-06-2012	26-06-2012	8	8
29262	16-07-2012	16-07-2012	1	1
29266	19-07-2012	02-03-2013	223	45
29259	20-09-2012	13-06-2013	263	177
29260	20-09-2012	13-06-2013	263	150
29261	20-09-2012	11-06-2013	261	97
41670	20-09-2012	15-01-2013	115	99

Acoustic Tag #	First Detection	Last Detection	# Days Between First and Last Detection	# Days with Detections
41685	07-10-2012	13-12-2012	66	17
41640	30-11-2012	30-11-2012	1	1
41690	17-05-2013	12-06-2013	25	25
41691	05-06-2013	13-06-2013	8	8
41692	05-06-2013	13-06-2013	8	8

Table 4. Observations from SCUBA surveys on wolffish distribution, behaviour, habitat characteristics and use.

Location	Date	Latitude	Longitude	Depth (m)	Dive Time (min.)	Surface Water Temperature (oC)	Bottom Water Temperature (oC)	Wolffish Sighting	Den	Egg Cluster	Prey	Other Fauna	Seafloor
Torbay	09-07-2009	47.6750	-52.7180	12	20	8.8	8.8	-	-	-	-	-	-
Torbay	09-07-2009	47.6750	-52.7180	11	18	10	8.9	-	-	-	-	Juvenile Cod	-
Flatrock	16-07-2009	47.7014	-52.7043	11	32	16.5	15.8	-	-	-	Shellfish	-	-
Flatrock	21-07-2009	47.7014	-52.7043	17	29	15.5	11.1	-	-	-	-	Cunners	-
Torbay	20-08-2009	47.6750	-52.7180	20	30	15.6	10.5	-	-	-	-	Jellyfish, eelpouts, sculpins and schools of juvenile cod	-
Torbay	01-09-2009	47.6750	-52.7180	17	27	15.6	10.6	-	-	-	-	Capelin and cod	-
Bauline	15-07-2010	47.7227	-52.8351	15	35	0	0	-	-	-	-	-	-
Bauline	06-08-2010	47.7251	-52.8344	15	27	10	10	1 Atlantic Wolffish	-	-	Lobsters	Winter skate	-
Bauline	09-08-2010	47.7243	-52.8343	23	30	10	10	2 Atlantic Wolffish	-	-	-	-	-
Bauline	11-08-2010	47.7227	-52.8351	18	25	10	15.6	-	-	-	Lobster	-	-
Bauline	30-08-2010	47.7227	-52.8351	15	20	NA	NA	-	-	-	Mussels	-	-
Torbay	01-09-2010	47.6750	-52.7180	23	36	NA	NA	-	-	-	Lobsters	-	-
Bauline	20-10-2010	47.7227	-52.8351	17	38	NA	5.6	-	-	-	Lobsters and mussels	-	-
Bauline	19-11-2010	47.7227	-52.8351	16	31	NA	3.9	-	-	-	-	-	-
Bauline	14-12-2010	47.7227	-52.8351	5	30	NA	1.1	-	-	-	-	-	-
Bauline	15-12-2010	47.7227	-52.8351	17	32	NA	1.1	-	-	-	-	-	-
Bauline	21-04-2011	47.7227	-52.8350	14	25	0.6	-0.6	-	-	-	-	-	-
Bauline	29-06-2011	47.6958	-52.8498	14	26	NA	4.4	3 Atlantic Wolffish	-	-	-	-	flat bottom, small boulders, mossy seaweed over bottom

Location	Date	Latitude	Longitude	Depth (m)	Dive Time (min.)	Surface Water Temperature (oC)	Bottom Water Temperature (oC)	Wolffish Sighting	Den	Egg Cluster	Prey	Other Fauna	Seafloor
Torbay	19-07-2011	47.6750	-52.7180	20	27	NA	0.6	-	-	-	Sea urchins	-	rocky bottom, corals present, steep slope
Bauline	28-07-2011	47.7227	-52.8350	14	26	14.3	11.6	-	-	-	-	-	rocky bottom, big boulders
Bauline	16-08-2011	47.6960	-52.8503	20	23	NA	8.3	-	-	-	-	-	Steep slope bottom
Bauline	16-08-2011	47.7285	-52.8439	16	25	NA	7.8	-	-	-	-	-	Big boulders
Bauline	22-08-2011	47.6955	-52.8499	16	25	NA	7.8	-	-	-	Sea urchins, anemones, mussels	-	-
Torbay	25-08-2011	47.6750	-52.7180	15	20	NA	NA	-	-	-	-	-	-
Bauline	05-09-2011	47.7227	-52.8351	19	32	NA	0	-	-	-	Lobsters	-	-
Bauline	21-10-2011	47.7227	-52.8351	19	36	7.2	7.8	-	1 Atlantic Wolffish in den	-	Urchins and mussels	Winter skates	Rocky bottom
Bauline	24-10-2011	47.7227	-52.8351	22	36	7.8	7.8	-	1 Atlantic Wolffish in den	-	Lobsters	Cunners	Rocky bottom
Bauline	25-10-2011	47.7227	-52.8351	19	31	7.8	7.8	-	1 Atlantic Wolffish in den	egg cluster in den	-	-	Rocky bottom
Bauline	01-05-2012	47.7227	-52.8351	16	34	NA	NA	-	-	-	-	-	Rocky bottom
Bauline	09-05-2012	47.7227	-52.8351	19	32	NA	0	-	-	-	Lobsters	-	Rocky bottom
Bauline	25-05-2012	47.7227	-52.8351	8	20	0	0	-	-	-	-	-	Rocky bottom
Torbay	22-06-2012	47.6750	-52.7180	22	36	6.1	5.6	1 Atlantic Wolffish	-	-	-	Capelin	-
Bauline	11-07-2012	47.7227	-52.8351	17	42	12.8	10.6	-	2 Atlantic Wolffish in den	-	-	-	Rocky bottom
Bauline	12-07-2012	47.7227	-52.8351	16	42	16.8	15.5	-	-	-	-	-	Rocky bottom
Bauline	12-07-2012	47.7227	-52.8351	20	49	12.2	10	-	4 Atlantic Wolffish in 3 dens	-	-	-	Rocky bottom
Bauline	16-07-2012	47.7227	-52.8351	20	36	NA	12.8	-	4 Atlantic Wolffish in 3 dens	-	-	-	Rocky bottom

Location	Date	Latitude	Longitude	Depth (m)	Dive Time (min.)	Surface Water Temperature (oC)	Bottom Water Temperature (oC)	Wolffish Sighting	Den	Egg Cluster	Prey	Other Fauna	Seafloor
Bauline	16-07-2012	47.6960	-52.8503	11	39	NA	8.3	1 Atlantic Wolffish	-	-	Sea urchins	-	Rocky bottom
Bauline	24-08-2012	47.7227	-52.8351	18	31	NA	NA	-	-	-	-	-	-
Bauline	31-08-2012	47.7227	-52.8351	17	28	NA	14.9	-	-	-	-	-	-
Bauline	23-10-2012	47.7227	-52.8351	17	15	NA	15	-	1 Atlantic Wolffish in den	-	-	-	Rocky bottom
Bauline	25-06-2013	47.7227	-52.8351	16	39	9	7	-	2 Atlantic Wolffish in den	-	-	-	Rocky bottom
Bauline	19-07-2013	47.7227	-52.8351	16	42	20	12	-	1 Atlantic Wolffish in den	-	-	-	Rocky bottom

FIGURES

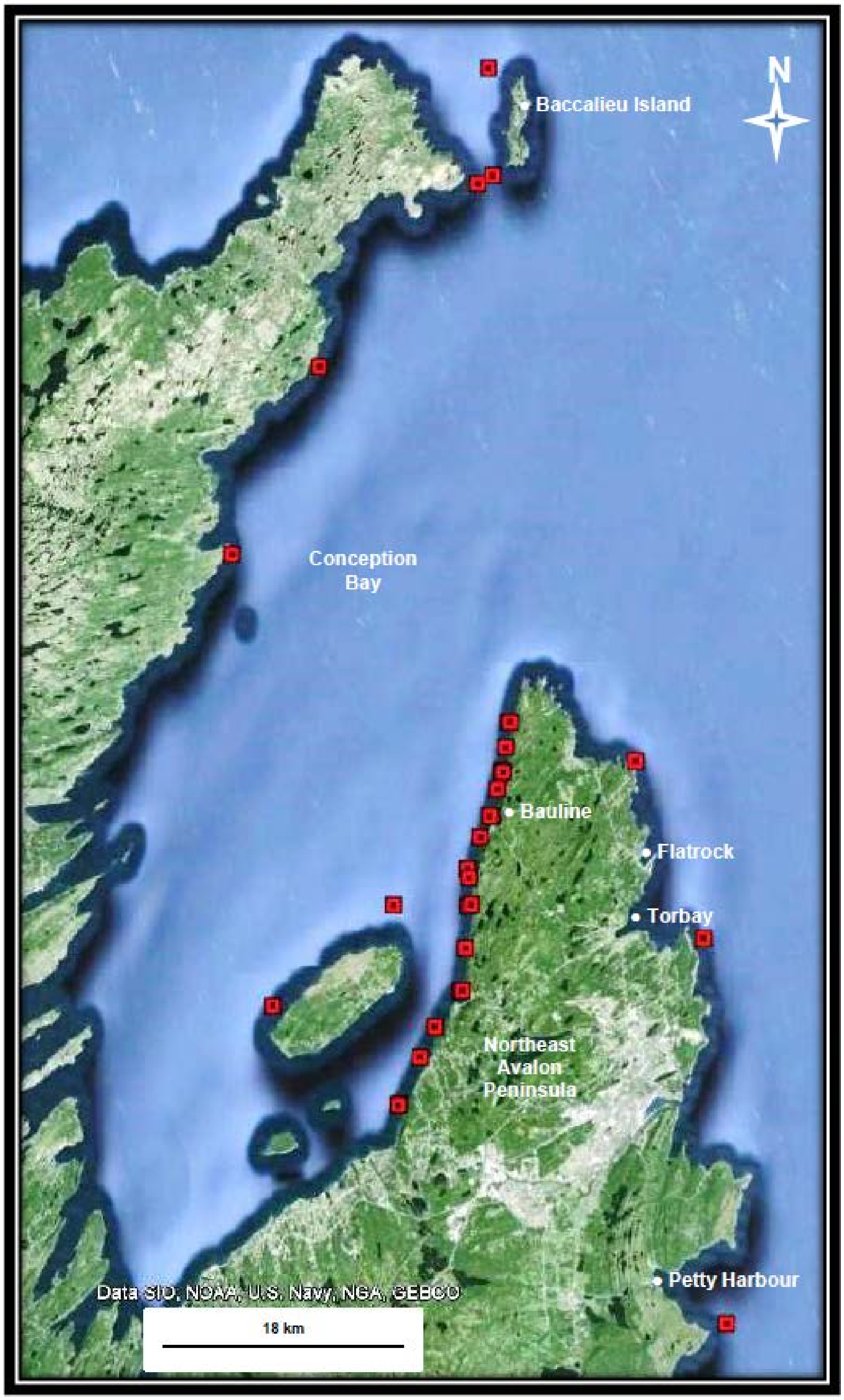

Figure 1. Map of the sites of moored hydrophone arrays (red squares) along the Northeast Avalon Peninsula (NF) and geographic locations mentioned in the text.

Figure 2. Map showing the distribution patterns of wolffish in the study area (red squares), as inferred from telemetry data (2011-2013).Data represent wolffish detected at one or more hydrophone stations.

Figure 3. Map showing the distribution (blue circles) and movement of wolffish at ranges < 4 km, as inferred from telemetry data (2011-2013) Data represent wolffish detected at one or more hydrophone stations.

Figure 4. Map showing the distribution (red circles) and movement of wolffish at intermediate ranges (4-20 km), as inferred from telemetry data (2011-2013) Data represent wolffish detected at two or more hydrophone stations. Movement patterns (white lines) of 3 wolffish fish (acoustic tag # 29256, 41648 and 60782) are shown in insets.

Figure 5. Map showing the distribution (yellow circles) and movement (white lines) of wolffish at ranges > 20 km, as inferred from telemetry data (2011-2013) Data represent wolffish detected at two or more hydrophone stations.

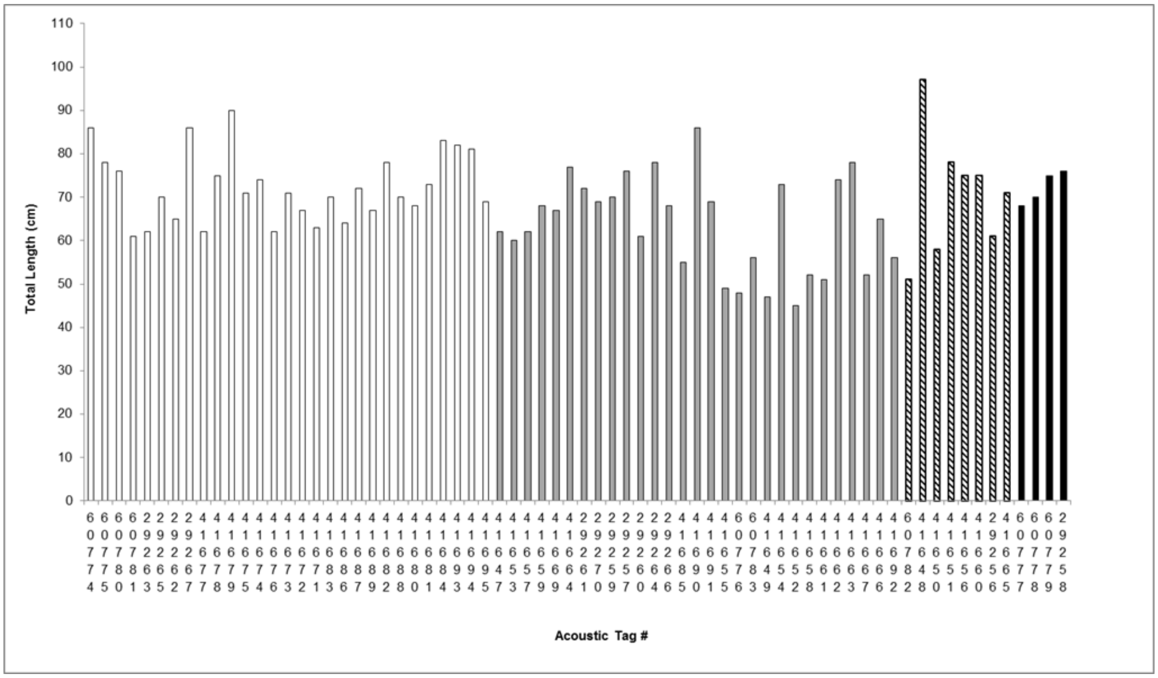

Figure 6. Length frequency distribution of wolffish tagged (white bar) and subsequently detected at various hydrophone stations. Distance travelled between location of release and detection: <4 km (grey bar), 4-20 km (dashed bar), > 20 km (black). Data are presented in chronological order (i.e. sorted by date of capture).

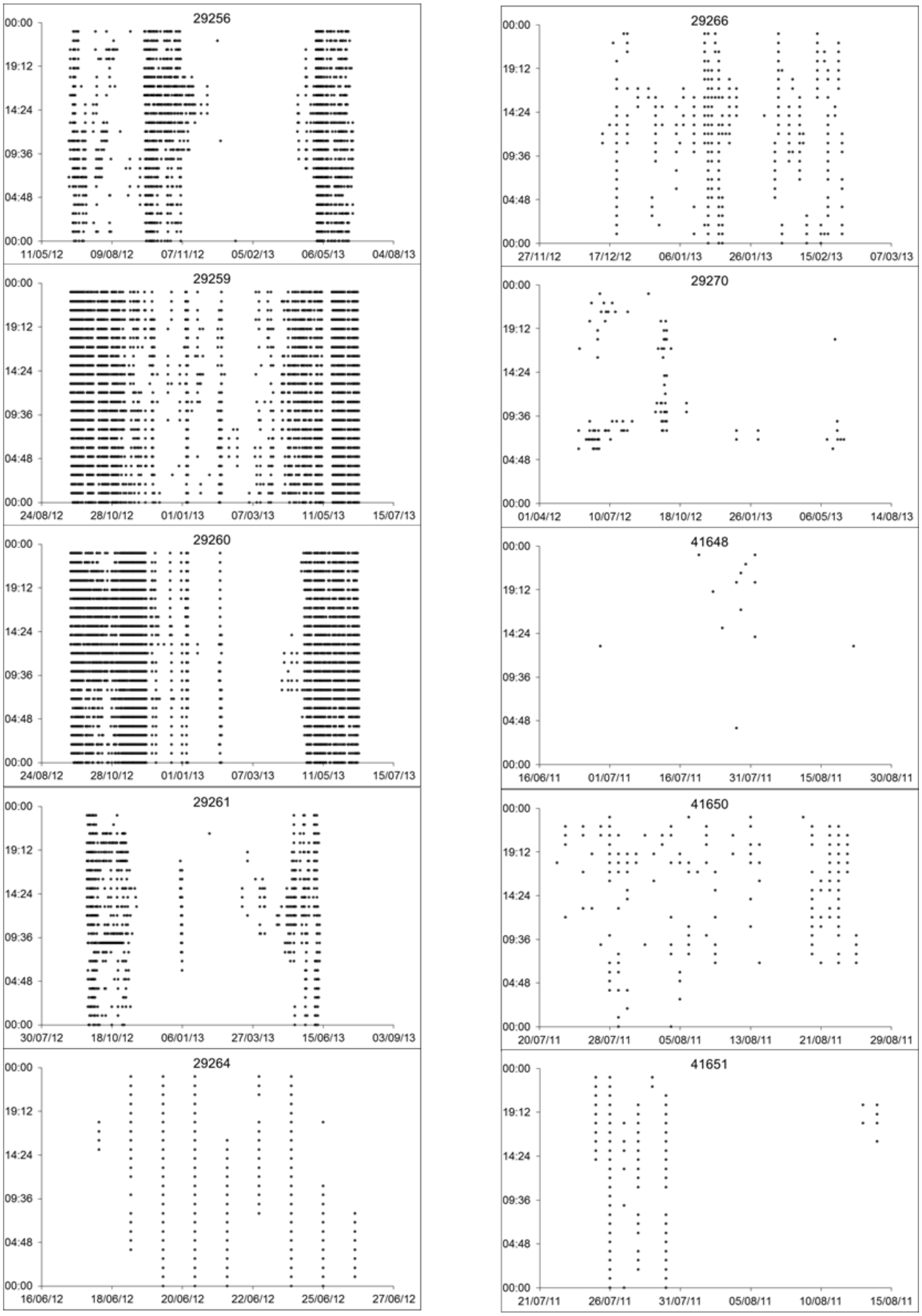

Figure 7-A. Small-scale temporal patterns of wolffish at various hydrophone stations, as inferred from telemetry data (2011-2013). Each panel shows the daily (1 hour average) acoustic detections (y-axis) for a single wolffish (tag # shown on the top of the panel). Data are presented for wolffish whose detections occurred over several days or longer (x-axis).

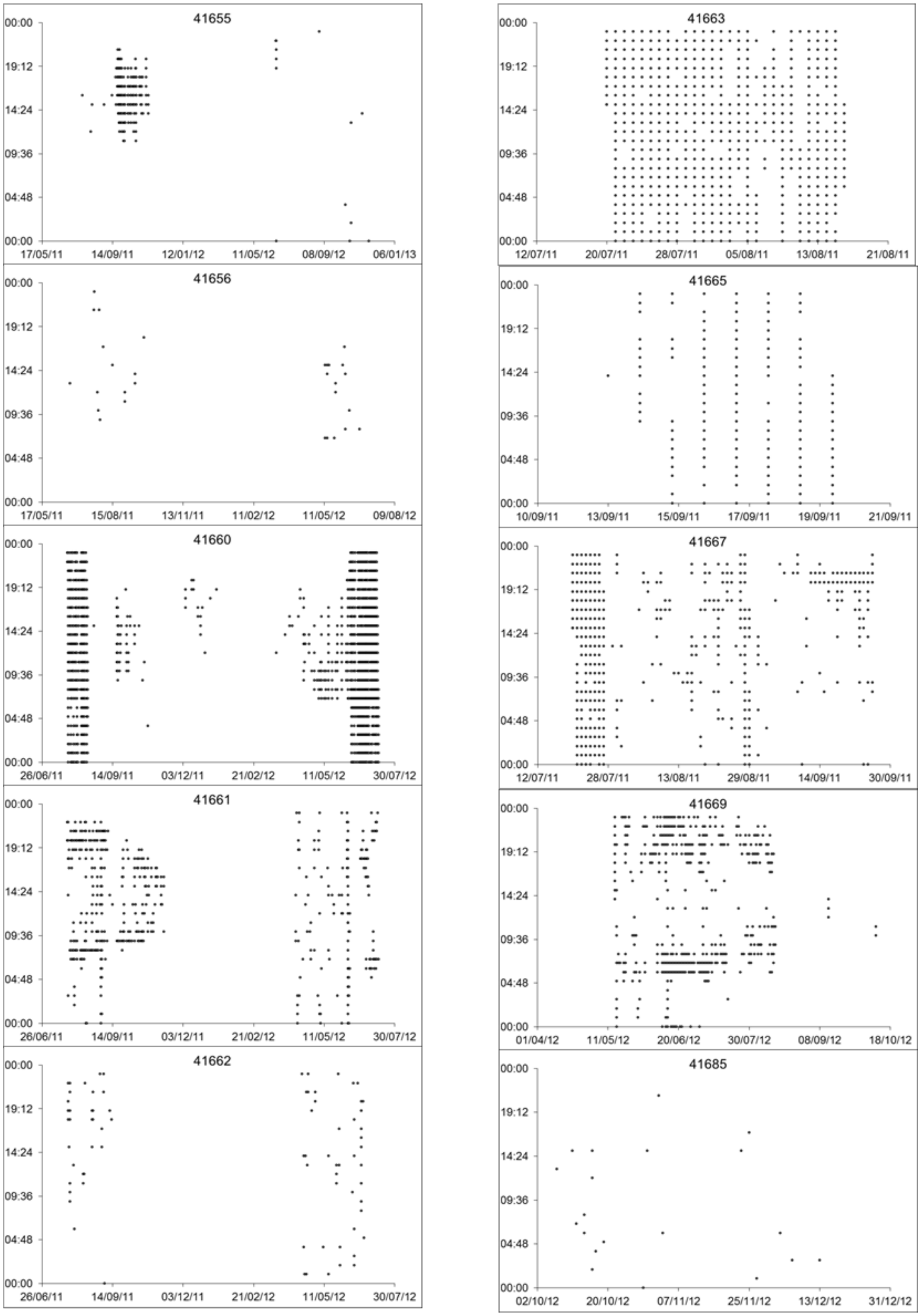

Figure 7-B. Small-scale temporal patterns of wolffish at various hydrophone stations, as inferred from telemetry data (2011-2013). Each panel shows the daily (1 hour average) acoustic detections (y-axis) for a single wolffish (tag # shown on the top of the panel). Data are presented for wolffish whose detections occurred over several days or longer (x-axis).

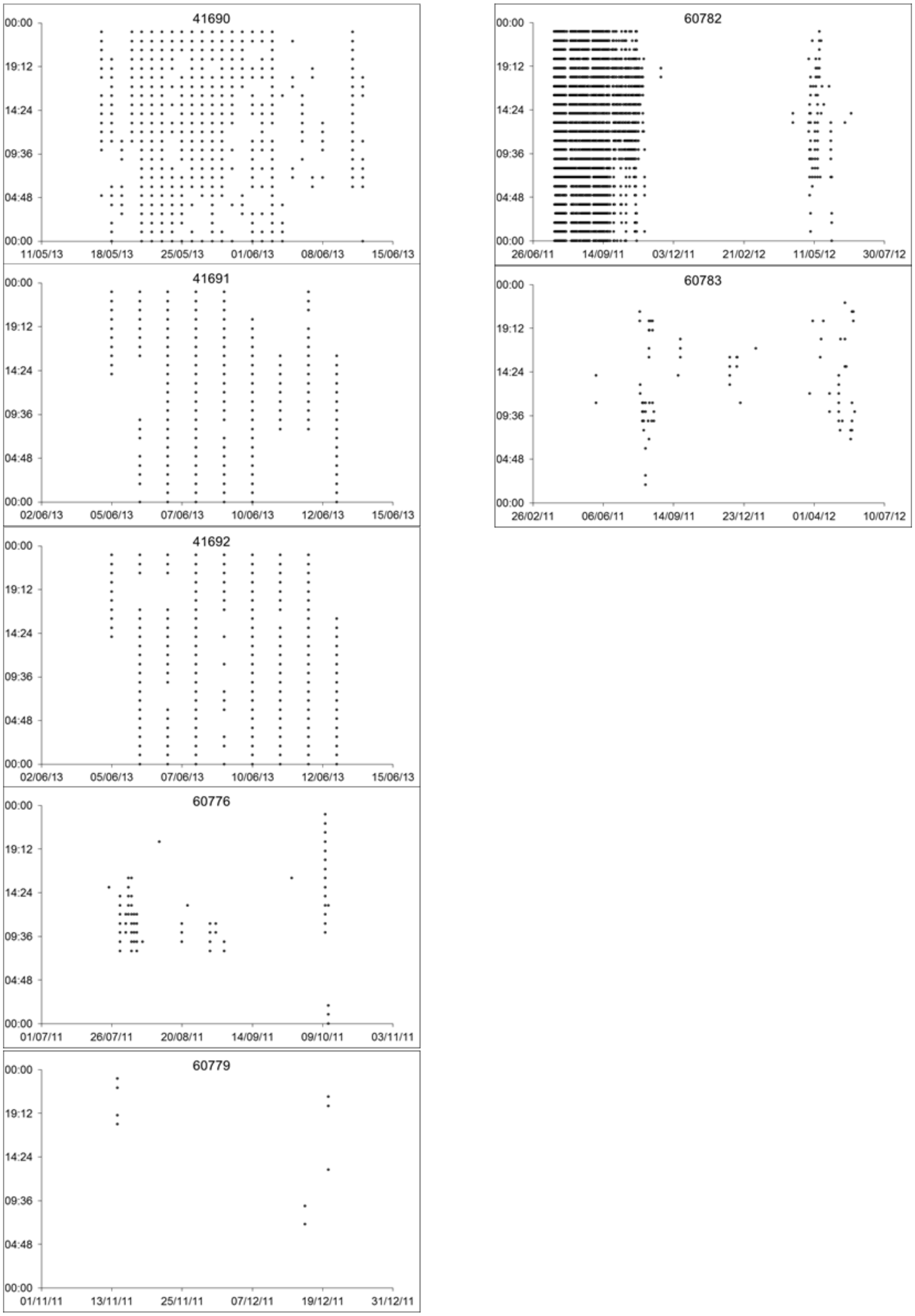

Figure 7-C. Small-scale temporal patterns of wolffish at various hydrophone stations, as inferred from telemetry data (2011-2013). Each panel shows the daily (1 hour average) acoustic detections (y-axis) for a single wolffish (tag # shown on the top of the panel). Data are presented for wolffish whose detections occurred over several days or longer (x-axis).

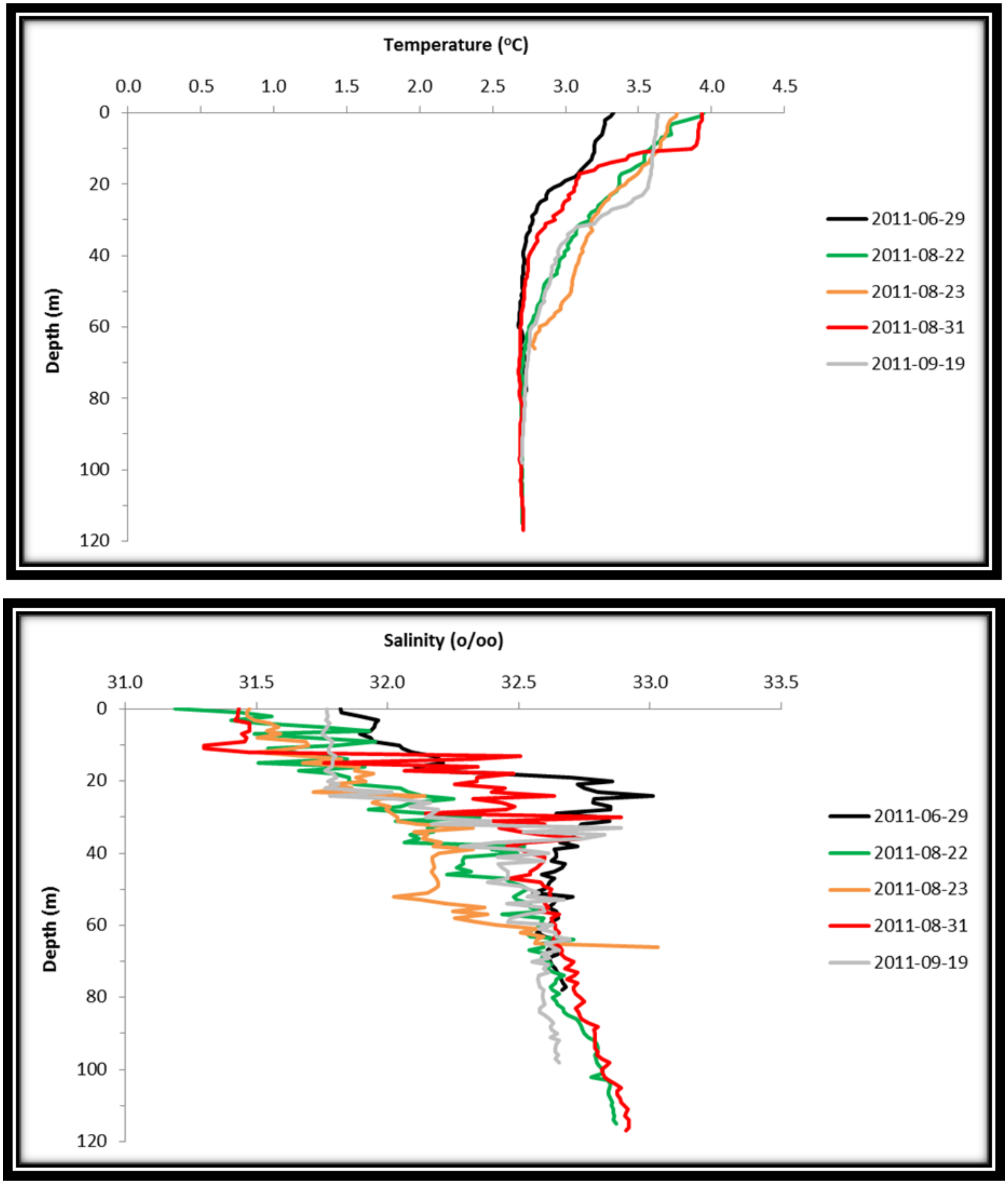

Figure 8. Vertical profile of water temperature and salinity in the study area in summer 2011.

Figure 9. Typical habitat where Atlantic Wolffish dens were found during SCUBA surveys in Conception Bay (NF). Note the rocky seafloor and steep slope, with the presence of boulders and crevices.

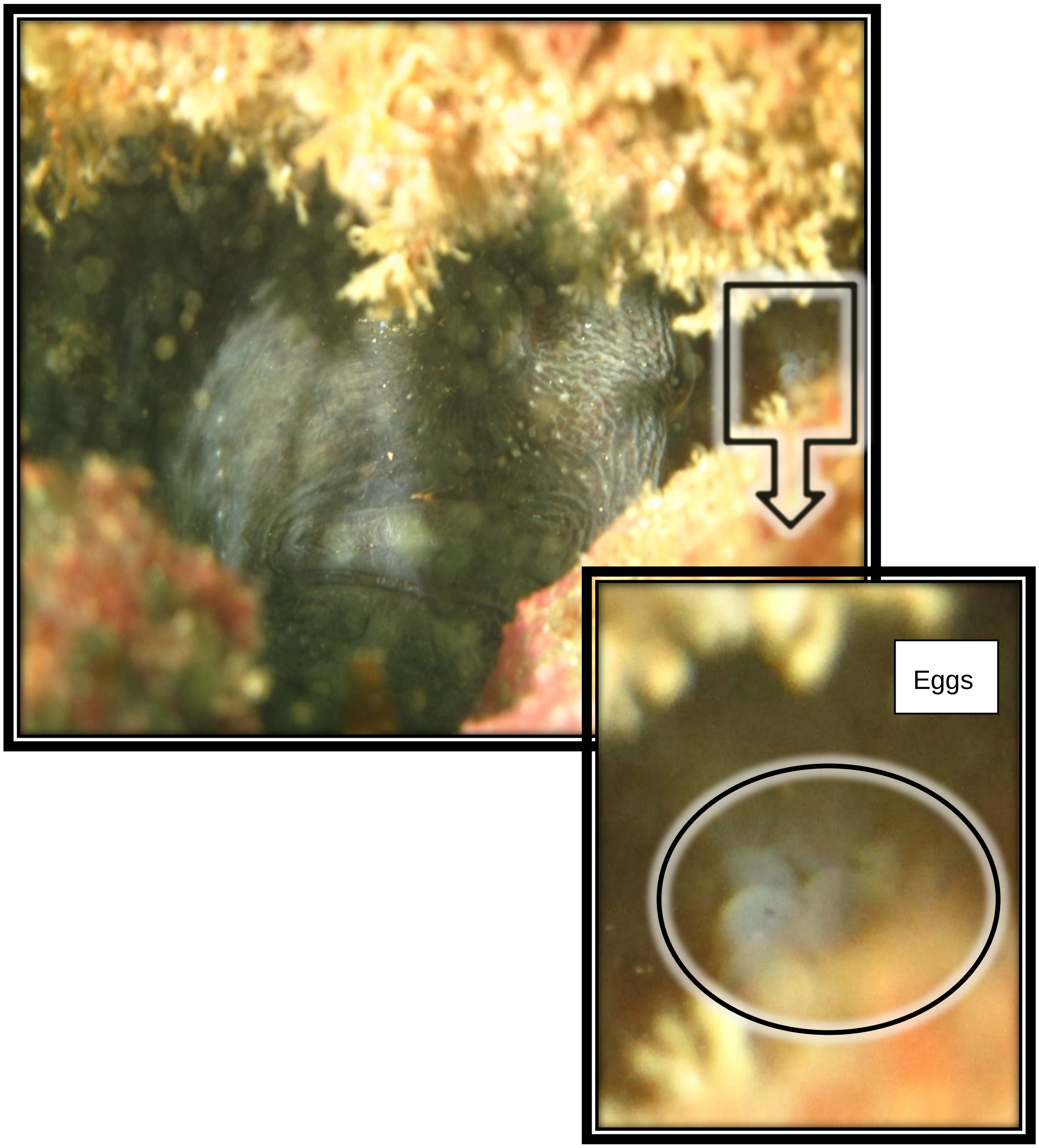

Figure10. Atlantic Wolffish inside a den guarding unhatched eggs. These pictures were taken during a SCUBA survey near Bauline, Conception Bay (NF), on October 25, 2011.

Figure 11. Feeding debris (bivalve shells, sea urchins) at the entrance of dens inhabited by Atlantic Wolffish in Conception Bay (NF).