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Northeast Multispecies Fishery Management Plan Resource Guide: Atlantic Wolffish (Anarhichas lupus)

Bibliography

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Background & Scope

The Northeast Multispecies Fishery Management Plan (FMP) was implemented in 1986 to reduce fishing mortality of heavily fished groundfish stocks and to promote rebuilding to sustainable biomass levels. Thirteen species are managed through plan amendments and framework adjustments to the original plan, including: Atlantic cod, haddock, yellowtail flounder, American plaice, witch flounder (grey sole), winter flounder (black back), Acadian redfish, white hake, Pollock, windowpane flounder, ocean pout, Atlantic halibut, and the Atlantic wolffish. This bibliography focuses on Atlantic wolffish, and is intended as a primer and reference resource for staff of the National Marine Fisheries Service, Greater Atlantic Regional Fisheries office. It is organized into four sections: Biology (life history), Ecology (interaction with the environment), Fishery, and Management.

Section I - Biology

Section one is intended to provide an overview of the life history of Atlantic wolffish. The research in this area is a compilation of basic facts including diet, lifespan and habitat as well as current research on Atlantic wolffish Biology.

Section II – Ecology

Section two is intended to provide an overview of how Atlantic wolffish interacts with the environment. The citations in this area focus on how temperature, food resources, and habitat loss have impacted wild Atlantic wolffish.

Section III – Fishery

Section three is intended to provide an overview of the Atlantic wolffish fishery. It contains both government reports and scientific publications about the current state of the Atlantic wolffish fishery.

Section IV – Management

Section four is intended to provide an overview of the management of the Atlantic wolffish fishery. It includes research concerning plans and policies intended to protect and restore the Atlantic wolffish population.

Sources Reviewed

Along with a web search for news items and other relevant materials the following databases were used to identify sources: Clarivate Analytics' Web of Science: Science Citation Index Expanded, ProQuest's Earth Atmospheric & Aquatic Science Database, and JSTOR. Only English language materials were included. There was no date range specification in order to cover any relevant research, although priority was given to publication in the last twenty years focusing on wild populations in the Atlantic region.

Section I: Biology

Image from: Fisheries and Ocean Canada (2017). Atlantic Wolffish. Retrieved from http://www.dfo-mpo.gc.ca/species-especes/profiles-profils/wolffish-loup-at-eng.html

Also known as: Ocean whitefish, Wolffish, Sea wolf, Sea-cat

Region: Northeast Atlantic: Spitsbergen southward to White Sea, Scandinavian coasts, North Sea, the British Isles, also Iceland and south-eastern coasts of Greenland. Northwest Atlantic: southern Labrador in Canada and western Greenland to Cape Cod in Massachusetts, USA; rarely to New Jersey, USA, elsewhere in the Baltic Sea (east to Rügen and Bornholm Islands), Bay of Biscay and northwestern Mediterranean (Gulf of Genoa).

Source: Luna, S. M. (2017) Anarhichas lupus Linnaeus 1758 Atlantic Wolffish. Retrieved from http://www.fishbase.org/summary/Anarhichas-lupus.html

Habitat: Atlantic wolfish can be found to depths of 500 meters, but prefer depths of 80-120 meters. They also appear to prefer areas with complex bottom substrates such as rocky outcroppings or seaweed beds.

Size: Atlantic wolfish can grow of 59 inches and 40 pounds

Physical Description: With color varying from slate-blue to purplish brown or olive green, Atlantic wolfish have firm musculature and dark transverse bars on their body. They have canine teeth, a cluster of 5-6 canines behind the primary canine teeth, and three sets of crushing teeth on the roof of their mouth. Wolffish produce natural antifreeze that allows them to live in extremely cold environments.

Lifespan: Atlantic wolfish may live up to 20 years.

Diet: Mollusks, crustaceans, echinoderms, and less frequently, fish.

Source: National Marine Fisheries Service. (2009)Species of Concern: Atlantic Wolffish, Anarhichas lupus. Retrieved from http://www.nmfs.noaa.gov/pr/pdfs/species/atlanticwolffish_detailed.pdf

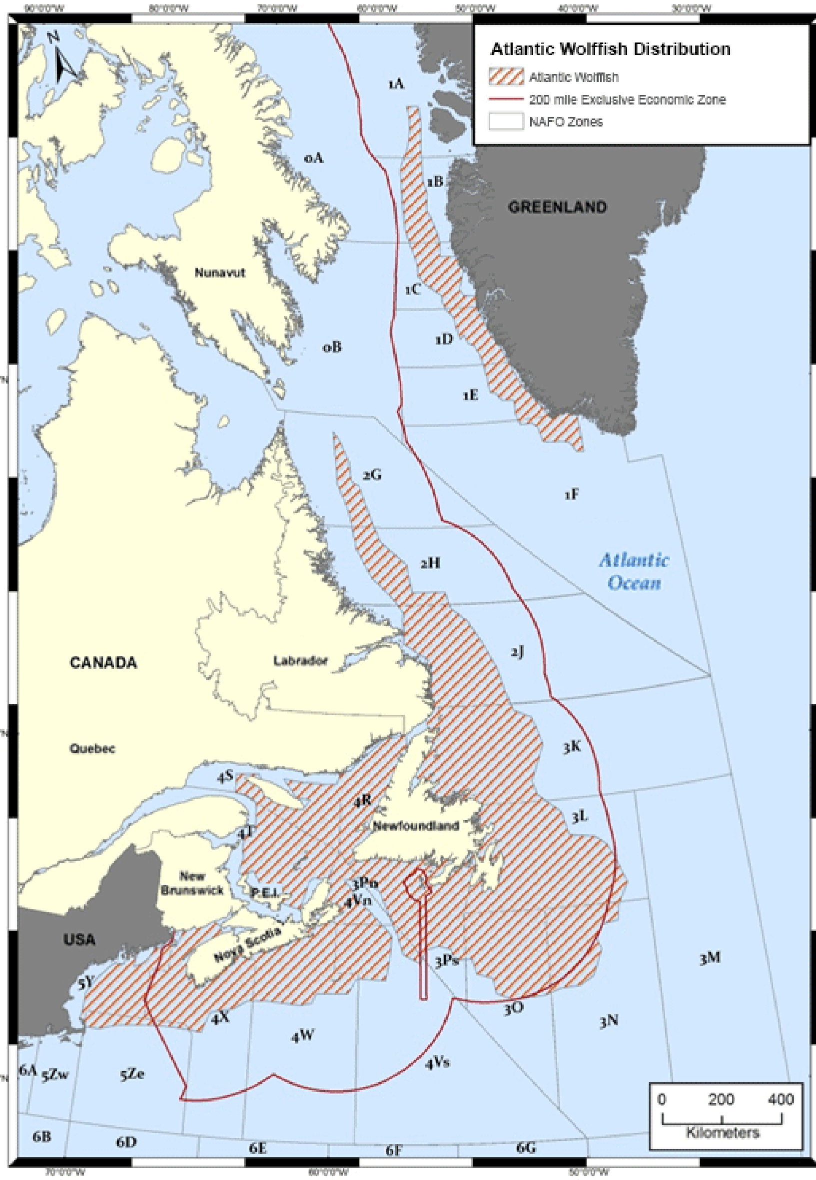

Image from: Fisheries and Ocean Canada (2017). Atlantic Wolffish. Retrieved from http://www.dfo-mpo.gc.ca/species-especes/profiles-profils/wolffish-loup-at-eng.html

Hellberg, H., Bjerkås, I., Vågnes, Ø. B., & Noga, E. J. (2013). Mast cells in common wolffish Anarhichas lupus L.: Ontogeny, distribution and association with lymphatic vessels. Fish & Shellfish Immunology, 35(6), 1769-1778. https://doi.org/10.1016/j.fsi.2013.08.031

The morphology, ontogeny and tissue distribution of mast cells were studied in common wolffish (Anarhichas lupus L.) at the larval, juvenile and adult life stages using light and electron-microscopy and immunohistochemistry. Fish were sampled at 1 day, 1, 2, 3, 4, 8 and 12 weeks post-hatching in addition to 6 and 9 months and 2 years and older. From 8 weeks post-hatching, mast cells in common wolffish mainly appeared as oval or rounded cells 8–15 μm in diameter with an eccentrically placed, ovoid nucleus and filled with cytoplasmic granules up to 1.2 μm in diameter. Granules were refractile and eosinophilic to slightly basophilic in H&E and stained bright red with

Martius-scarlet-blue and purple with pinacyanol erythrosinate in formalin-fixed tissues. Mast cells stained positive for piscidin 4 and Fc ε RI by immunohistochemistry. From 1 day to 4 weeks post-hatching, immature mast cell containing only a few irregularly sized cytoplasmic granules were observed by light and electron-microscopy in loose connective tissue of cranial areas. From 1 day post-hatching, these cells stained positive for piscidin 4 and Fc ε RI by immunohistochemistry. From 12 weeks post-hatching, mast cells showed a primarily perivascular distribution and were particularly closely associated with lymphatic vessels and sinuses. Mast cells were mainly located at the peripheral border of the adventitia of arteries and veins, while they were in intimate contact with the endothelium of the lymphatic vessels. Numerous mast cells were observed in the intestine. A stratum compactum, as described in salmonids, was not observed in wolffish intestine, nor were mast cells confined to a separate layer, a stratum granulosum. Lymphatic vessels consisting of endothelium, intimal connective tissue and a poorly developed basal lamina were observed in the intestine. Scanning electron microscopy was used to compare the structure and localization of intestinal mast cells of common wolffish and rainbow trout. Scanning electron microscopy also revealed endothelial surface features and confirmed the existence of three distinctly different types of vessels in the wolffish intestine. Rainbow trout mast cell granules appeared as intact globular structures while empty vacuoles were observed in common wolffish. Mast cells were closely associated with lymphatic vessels in common wolffish, but not in rainbow trout.

Desjardins, M., Graham, L. A., Davies, P. L. and Fletcher, G. L. (2012), Antifreeze protein gene amplification facilitated niche exploitation and speciation in wolffish. FEBS Journal, 279: 2215–2230. https://doi.org/10.1111/j.1742-4658.2012.08605.x

During winter, the coastal waters of Newfoundland can be considered a 'freeze risk ecozone' for teleost fishes, where the shallower habitats pose a high (and the deeper habitats a low) risk of freezing. Atlantic (*Anarhichas lupus*) and spotted (*Anarhichas minor*) wolffish, which inhabit these waters, reside at opposite ends of this ecozone, with the Atlantic wolffish being the species facing the greatest risk, because of its shallower niche. In order to resist freezing, this species secretes five times the level of antifreeze protein (AFP) activity into the plasma than does the spotted wolffish. The main basis for this interspecific difference in AFP levels is gene dosage, as the Atlantic wolffish has approximately three times as many AFP gene copies as the spotted wolffish. In addition, *AFP* transcript levels in liver (the primary source of circulating AFPs) are several times higher in the Atlantic wolffish. One explanation for the difference in gene dosage and transcript levels is the presence of tandemly arrayed repeats in the latter, which make up two-thirds of its AFP gene pool. Such repeats are not present in the spotted wolffish. The available evidence indicates that the two species diverged from a common ancestor at a time when the ebb and flow of northern glaciations would have resulted in the emergence of shallow water 'freeze risk ecozones'. The results of this study suggest that the duplication/amplification of AFP genes in a subpopulation of ancestral wolffish would have facilitated the exploitation of this high-risk habitat, resulting in the divergence and evolution of modern-day Atlantic and spotted wolffish species.

Le François, N. R., Lamarre, S. G., Tveiten, H., Blier, P. U., & Bailey, J. (2008). Sperm cryoconservation in Anarhichas sp., endangered cold-water aquaculture species with internal fertilization. Aquaculture International, 16(3), 273-279. https://doi.org/10.1007/s10499-007-9137-7

This study contributes to the identification of an adequate cryopreservation medium for wolffishes sperm (*Anarhichas minor* and *A. lupus*). Our results also confirm the presence of antifreeze proteins in the seminal fluid of the Atlantic wolffish (*Anarhichas lupus*) that could facilitate the process of cryoconservation in association with increased post-thaw motility and fertilization rates. Cryo-Fish, a commercial diluent was the most efficient in our trials, with 80% motility post-thaw.

O'Dea, N. R., & Haedrich, R. L. (2002). A review of the status of the Atlantic Wolffish, Anarhichas lupus, in Canada. Canadian Field-Naturalist, 116(3), 423-432.

The Atlantic Wolffish, Anarhichas lupus Linneaus, 1758, is a large blenny-like marine fish found in moderately deep and cold waters of the North Atlantic on rocky and hard bottoms from the Gulf of Maine to northwestern France. Wolffish was once the target of a directed fishery, but is not at present; nonetheless, it continues to be taken incidentally as by-catch in the trawl fishery. In Canadian waters, it has been most abundant off Newfoundland and Labrador, where it is a characteristic member of the deep cold-water fish assemblage on the continental shelf, but its numbers there, as indicated by scientific surveys, declined by 91% between 1978 and 1994. In other Canadian areas, where wolffish abundance has historically been lower by about an order of magnitude, populations appear stable. Wolffish are relatively sedentary and slow-growing. They make nests, and guard their large eggs. They feed mostly on bottom invertebrates. Life histories and distribution patterns can vary considerably across the species' range. Aggressive trawl fisheries, now in abeyance by the imposition of widespread moratoriums, appear to have had an impact on wolffish numbers. In the Newfoundland region, numbers have declined steadily in scientific surveys, the number of locations where the species occurs is fewer, the range where abundant appears to be shrinking, and the mean size has decreased so that mature individuals have become relatively rare. Slow growth, fidelity and inshore nesting habit, and limited dispersal make rescue unlikely, and bottom trawling and dredging have probably damaged habitat.

Section II: Ecology

Novaczek, E., Devillers, R., Edinger, E., & Mello, L. (2017). High-resolution seafloor mapping to describe coastal denning habitat of a Canadian species at risk: Atlantic wolffish (Anarhichas lupus). Canadian Journal of Fisheries and Aquatic Sciences, 74(12), 2073-2084. https://doi.org/10.1139/cjfas-2016-0414

The Atlantic wolffish (Anarhichas lupus) is listed by Canada's Species at Risk Act as a species of special concern. Effective conservation strategies rely on accurate knowledge of habitat requirements, distribution, and vulnerabilities; however, current management plans cite lack of wolffish habitat data as a key limitation. For this study, coastal Atlantic wolffish denning habitat was characterized and mapped with high-resolution multibeam data and seafloor video in Conception Bay, Newfoundland. Four Atlantic wolffish dens, used for feeding, spawning, and egg-guarding, were surveyed and mapped. On the basis of the geomorphology and substrate of these dens, a supervised classification was applied to the multibeam bathymetry and backscatter data to identify other potential denning areas. Predicted denning habitat, limited by the occurrence of suitable rocky substrate, is most prevalent in shallow waters (<22 m) distributed over 1.6 km (2) (5.9%) of the study area. Shallow denning habitat is exposed to seasonal maximum temperatures that exceed the threshold for normal Atlantic wolffish egg development, a potential vulnerability for nearshore wolffish. As management efforts progress, this information will guide research and prioritization of conservation areas.

Bianucci, L., Fennel, K., Chabot, D., Shackell, N., & Lavoie, D. (2016). Ocean biogeochemical models as management tools: a case study for Atlantic wolffish and declining oxygen. Ices Journal of Marine Science, 73(2), 263-274. https://doi.org/10.1093/icesjms/fsv220

Society is moving towards a no-analogue climate that will fundamentally affect ocean ecosystems and the socio-economic activities that depend on them. Warming has led to displacements of various populations, calling for an adaptation of fisheries management plans and Species at Risk recovery strategies. Dissolved oxygen (DO) has declined, but its impacts on habitat are much less studied. Severe hypoxia is lethal, but even sublethal hypoxia can trigger species displacements. We use Atlantic wolffish (Anarhichas lupus) as a case study to investigate the impact of DO on optimal habitat on the Scotian Shelf, Canada, considering that their habitat becomes suboptimal at DO lower than similar to 65% saturation. First, we demonstrate that DO has decreased using two observational climatologies before and after 1980, and that the spatial pattern of the associated expansion of low oxygen waters (DO< similar to 65% saturation) over the shelf is consistent with the observed contraction of Wolffish population. Then, we use a spatially explicit regional ocean model that couples physical and biological processes to simulate a scenario in which a continued decline of DO in the open ocean leads to a further expansion of low oxygen waters over the shelf. The future low DO extends to regions that currently have high Wolffish biomass, and likely other species as well. While fishing pressure likely drives the observed decline in Wolffish, both observations and model scenario suggest that DO can further constrain habitat. We argue that management/recovery plans should consider DO as one of the potential stressors of not just Atlantic wolffish but any oxygen-sensitive species. Finally, we emphasize that biogeochemical ocean models can inform management by elucidating the direction and ranges of future changes in ocean environmental conditions.

Dutil, J. D., Proulx, S., Chouinard, P. M., Borcard, D., & Larocque, R. (2014). Distribution and environmental relationships of three species of wolffish (Anarhichas spp.) in the Gulf of St. Lawrence. Aquatic Conservation-Marine and Freshwater Ecosystems, 24(3), 351-368. https://doi.org/10.1002/aqc.2370

This study examines the spatial distribution of three species of wolffish in the Gulf of St. Lawrence on the basis of trawl surveys. A standardized method is proposed to assess species-habitat associations for the purpose of management and recovery of endangered marine species. Catch data (presence/absence in trawl sets) and landscape and environmental characteristics of the sea floor were aggregated using a common grid (100 km2 cells), and species-habitat relationships were explored using geospatial tools. Relative occurrence was lower and area of occupancy and concentration were much smaller for the northern wolffish (Anarhichas denticulatus) than for the spotted wolffish (Anarhichas minor), with the striped wolffish (Anarhichas lupus) being most widespread. Significant relationships were observed between values of the local spatial autocorrelation Gi* statistic and habitat descriptors for each of the three species. Hot spots for spotted and striped wolffish occurred in areas where a greater diversity of relief and habitats was found. They were associated with intermediate depths, coarse sediments and rock outcrops, and lower salinities and temperatures than for northern wolffish. Northern wolffish appeared to be associated mainly with the deep water sloped habitat bordering deep channels, whereas spotted and striped wolffish both concentrated most intensively into neighbouring deep water shelf habitats and relatively cold shallow to mid-depth shelf habitats of the northern Gulf. The RDA analysis indicated a significant relationship between Gi* scores of the three species and environmental variables. The model explained 52% of the variability in the data; northern wolffish showed a distinct relationship compared with the two other species. The conservation of marine species and protection of their habitats pose a major challenge given the limited amount of information typically available on rare species and the scale and complexity of marine processes that affect those species. The broad-scale approach presented here allows the provision of advice on important habitats on the basis of the best available knowledge.

Ames, T. (2010). Multispecies Coastal Shelf Recovery Plan: A Collaborative, Ecosystem-Based Approach. Marine and Coastal Fisheries, 2(1), 217-231. https://doi.org/10.1577/C09-052.1

This article explains the integration of an ecosystem into a collaborative management plan to restore New England's depleted multispecies groundfish stocks and decimated coastal fishery. Applying lessons learned from Maine's successful fishery for lobsters Homarus americanus, the Downeast Groundfish Initiative (an eclectic group of fishermen, scientists, and concerned individuals) created a new groundfish management approach designed to nest seamlessly within existing federal and state management systems and be compatible with a total allowable catch (TAC) approach, though it does not require TAC as the primary management tool. The plan resolves fine-scale issues affecting the fishery's biological productivity and addresses the economic, social, and cultural factors confronting fishing communities. The inadequacy of systemwide assessments in detecting local changes in marine ecosystems led to the creation of smaller, contiguous coastal shelf management units each of which encompasses the subpopulation of a key species such as Atlantic cod Gadus morhua. Each unit would have an inshore core layer encompassing the species' spawning grounds and nursery habitats while providing a limited, small-scale fishery for local fishermen using selective, habitat-friendly gear. A buffer layer outside the core area that brackets coastal shelf migration routes would also support a fishery using all legal gear types but with constraints, and an outer layer would provide a fishery operating under current federal regulations. The core and buffer areas would be collaboratively managed to enhance local stock recovery by local advisory councils of fishermen functioning under state administration and regional council oversight. The coastal shelf plan synchronizes the needs of coastal ecosystems and fishermen by restoring species diversity and protecting critical habitats while rebuilding commercial stocks. The approach can create robust, sustainable fisheries for all user groups, resolve equity issues among fishermen, and revitalize the economies of fishing communities of all sizes.

Link, J. S. (2007). Underappreciated Species in Ecology: "Ugly Fish" in the Northwest Atlantic Ocean. Ecological Applications, 17(7), 2037-2060. http://www.jstor.org/stable/40062096.

Species shifts and replacements are common in ecological studies. Observations thereof serve as the impetus for many ecological endeavors. Many of the species now known to dominate ecosystem functioning were largely ignored until studies of those underappreciated species elucidated their critical roles. Recognizing the potential importance of underappreciated species has implications for functional redundancies in ecosystems and should alter our approach to long-term monitoring. One example of an applied ecological system containing species shifts, underappreciated species, and potential changes in functional redundancies is the topic of fisheries. The demersal component of many fish communities usually consists of high-profile and commercially valuable species that are targets of fisheries, plus a diverse group of lesser known species that have minimal commercial value and focus. Yet ecologically these traditionally nontargeted species are often a major biomass sink in marine ecosystems and can also be critical in the functioning of bentho-demersal food webs. I examined the biomass trajectories of several species of skates, cottids, lophiids, anarhichadids, zooarcids, and similar species in the northeast U.S. Atlantic ecosystem to determine whether their relative abundance has changed across the past four decades. Distribution and stomach contents of these species were also evaluated over time to further elucidate the relative importance of these species. Landings of these underappreciated bentho-demersal fish were also examined in comparison to those species that historically have been commercially targeted. Of particular emphasis was the evaluation of evidence for sequential stock depletion and the ramifications for functional redundancy for this ecosystem. Results indicate that some of these fish species are now the dominant piscivores, benthivores, and scavengers in this ecosystem. These formerly under-studied species generally have either maintained a consistent population size or have increased in abundance (and expanded in distribution) over the past several decades. Nontraditionally targeted fish species are an often overlooked but important component of bentho-demersal fish communities. Implications for the energy flow and resilience specifically for future fisheries and generally for harvesting biological resources are significant, remaining critical issues for the world's ecosystems.

McCarthy, I., Moksness, E., & Pavlov, D. A. (1998). The effects of temperature on growth rate and growth efficiency of juvenile common wolffish. Aquaculture International, 6(3), 207-218. https://doi.org/10.1023/a:1009202710566

The effects of temperature on the survival, growth rate and growth efficiency of larval and juvenile common wolffish, Anarhichas lupus L. were studied at 0-31 days and 9-12 months post-hatching, respectively. The influence of temperature regime during egg incubation on subsequent survival and growth was also examined. The fish were reared at constant water temperatures of 5, 8, 11 and 14 degrees C, and all groups were fed dry pellets. At age 1 month, maximum growth rates were observed at 11 and 14 degrees C. Growth rates and survival of early juveniles were dependent upon incubation history, high growth being obtained only if rearing temperature exceeded the temperature of egg incubation. In juveniles at age 9-12 months, the relationships between temperature and growth, and temperature and growth efficiency were parabolic: the optimum water temperatures for growth (T-opt.G) and growth efficiency (T-opt.GE) were 11 degrees C and 9.7 degrees C respectively. The growth rate and growth efficiency at these water temperatures were 0.9% day (-1) and 0.45 g weight gain per g food offered, respectively.

Hagen, N. T., & Mann, K. H. (1992). Functional response of the predators American lobster Homarus americanus (Milne-Edwards) and Atlantic wolffish Anarhichas lupus (L.) to increasing numbers of the green sea urchin Strongylocentrotus droebachiensis (Müller). Journal of Experimental Marine Biology and Ecology, 159(1), 89-112. https://doi.org/10.1016/0022-0981(92)90260-H

The predatory impact of the American lobster *Homarus americanus* and the Atlantic wolffish *Anarhichas lupus* on the green sea urchin *Strongylocentrotus droebachiensis* was investigated in a multifactorial experiment. Both predators exhibited either Type 2 or Type 3 functional responses to increasing prey density, but the magnitude of the response differed for the two predators, and for different prey sizes. Predation on large (>20 *mm*) sea urchins increased approximately three-fold, i.e., from 1.12 to 3.54 urchins·day−1 for wolffish, and from 0.35 to 0.97 urchins·day−1 for lobster, when prey density was increased sixfold, i.e., from 5 to 30 urchins·tank−1. Although more urchins were killed at the highest density, the proportion of available urchins that were killed dropped by ≈50%. Predation on small (≤20m) sea urchins was similar for both predators, increasing from ≈0.5 to ≈1.9 urchins·day−1 with increased prey density. In the lobster treatment, a rock crab, *Cancer irroratus* Say, was included as alternative prey. The lobsters killed 5.78% of the total number of available rock crabs, and 5.01% of the total number of available urchins, but lobster predation on urchins was nearly halved in replicates where the crab was killed. Experimental factors other than prey density and prey size, i.e., season; availability of food and physical refuges for the prey, and whether the prey had been fed or starved prior to the experiment, had no significant effects on the predation rates of either predator. These results are consistent with the hypothesis that green sea urchin outbreaks may be triggered by reductions in predation pressure. There was no evidence of significantly increased predation on morbid sea urchins although ≈1% of the experimental sea urchin population exhibited symptoms of amoeboid, *Paramoeba invadens* (Jones), disease.

Witman, J. D., & Sebens, K. P. (1992). Regional Variation in Fish Predation Intensity: A Historical Perspective in the Gulf of Maine. Oecologia, 90(3), 305-315. http://www.jstor.org/stable/4219979

Regional variation in the intensity of fish predation on tethered brittle stars and crabs was measured at 30-33 m depths in the rocky subtidal zone at seven sites representing coastal and offshore regions of the Gulf of Maine, USA. Analysis of covariance comparing the slopes of brittle star survivorship curves followed by multiple comparisons tests revealed five groupings of sites, with significantly greater predation rates in the two offshore than in the three coastal groups. Brittle stars tethered at the three offshore sites were consumed primarily by cod, Gadus morhua, with 60-100% prey mortality occurring in 2.5 h. In striking contrast, only 6-28% of brittle star prey was consumed in the same amount of time at the four coastal sites, which were dominated by cunner, Tautogolabrus adspersus. In several coastal trials, a majority of brittle star prey remained after 24 h. The pattern of higher predation offshore held for rock crabs as well with only 2.7% of tethered crabs consumed (? = 36) at coastal sites versus 57.8% of crabs (? = 64) consumed at offshore sites. Another important predatory fish, the wolffish, Anarhichas lupus, consumed more tethered crabs than brittle stars. Videos and time-lapse movies indicated that cod and wolffish were significantly more abundant at offshore than at coastal sites. Three hundred years of fishing pressure in New England has severely depleted stocks of at least one important benthic predator, the cod, in coastal waters. We speculate that this human-induced predator removal has lowered predation pressure on crabs and other large mobile epi benthos in deep coastal communities. Transect data in dictate that coastal sites with few cod support significantly higher densities of crabs than offshore sites with abundant cod.

Albikovskaya, L. K. (1982). Distribution and abundance of Atlantic wolffish, spotted wolffish and northern wolffish in the Newfoundland area. NAFO Scientific Council Studies Miscellaneous Selected papers, 3, 29-32.

Data from fixed-station bottom-trawl surveys in the Newfoundland area during 1971-80 were used to describe the distribution and abundance of Atlantic wolffish, spotted wolffish and northern wolffish by depth and temperature. The Atlantic wolffish was the most abundant of the three species, occurring mainly in depths of 1 01-350 m at temperatures of -0.4° to 4.0° C. The spotted wolffish was the least abundant, occurring in very small quantities mainly in 101-350 m at temperatures less than 5° C. The northern wolffish was most abundant in depths greater than 150 m at temperatures less than 5°C. Because of their widespread distribution, wolffish occur as by-catches in fisheries directed toward other groundfish species.

Section III: Fishery

Modern: The most recent scientific research shows that wolffish numbers in the United States have dropped precipitously over the last decade. Although wolffish are not targeted commercially, they are still caught unintentionally in nets as by-catch. According to NMFS, over 1,200 metric tons of wolffish were caught in 1983. In 2009, the last year for which data is available, U.S. landings declined 97 percent to only 31.6 metric tons. The other primary threat to the Atlantic wolffish is destructive modern fishing practices like otter trawling. Otter trawling uses enormous nets that are dragged through the ocean and along the seafloor, picking up or disturbing everything in their path. This gear is indiscriminate in the species it catches and highly destructive to fragile rocky bottom areas through which it drags. One scientist estimated that virtually every inch of the seafloor in the ocean waters off New England's coast was impacted by such gear between 1984 and 1990. Because wolffish live on the rocky seafloor and depend on its diverse features to hunt for prey and protect their young, the impact of trawling and dredging in these habitats is cataclysmic. So, even when the wolffish is not being caught as by-catch, damaging fishing gear can significantly limit the fish's reproductive success and survival.
Source: Conservation Law Foundation (2011). CLF Fact Sheet: Atlantic Wolffish. Retrieved from http://www.clf.org/wp-content/uploads/2013/03/Wolffish-fact-sheet.pdf

National Marine Fisheries Service (2016). Status of Stocks 2016. Retrieved from https://repository.library.noaa.gov/view/noaa/15620

Atlantic wolffish listed as overfished. Overfished is defined as: a stock that has a population size that is too low and that jeopardizes the stock's ability to produce its maximum sustainable yield.

Fairchild, E. A., Tallack, S., Elzey, S. P., & Armstrong, M. P. (2015). Spring feeding of Atlantic wolffish (Anarhichas lupus) on Stellwagen Bank, Massachusetts. . Fishery Bulletin, 113(2), 199-201. http://dx.doi.org/10.7755/FB.113.2.7

Full life history information is lacking for Atlantic wolffish (Anarhichas lupus), a species of concern in U.S. waters. Scientific studies indicate that Atlantic wolffish are found in low densities—either solitary or, during spawning season, paired. Groundfish surveys show wolffish abundance in U.S. waters is highest in the Gulf of Maine– Georges Bank region, especially in the southwestern portion at depths of 80–120 m. Contrary to these data, commercial fishermen have reported, and we have validated, that high concentrations of Atlantic wolffish are found in specific shallow locations and at specific times on the Stellwagen Bank National Marine Sanctuary (SBNMS) in Massachusetts Bay. From 53 tows conducted during May–June 2011, 395 Atlantic wolffish were captured on the SBNMS. Average daily catch per unit of effort ranged from 0.6 to 37.8 fish h^{-1} in an area characterized by shallow (depths: 27–46 m), cold (5–7°C) water, and a sand and gravel substrate. At this site, wolffish were mature (mean age: 20 years; range: 7–33 years) and in prespawning condition, both sexes were equally represented, and 99% of the fish were feeding actively. Total mortality (Z) estimated from the age frequency was 0.35. Considering the observed wolffish abundance and their feeding intensity, it appears that this area of the SBNMS is a foraging area used collectively by a large group of wolffish during May–June.

Department of Fisheries and Oceans, Canada. (2014). Wolffish in the Atlantic and Arctic Regions. Retrieved from http://www.dfo-mpo.gc.ca/csas-sccs/publications/sar-as/2014/2014_022-eng.html

Abundance indices for all three wolffish species throughout Canadian Atlantic and Arctic waters have been stable or at higher values since the mid-2000s compared to the 1990s. However, there are areas where catches are sporadic because the species are scarce and represent a minor portion of the overall population. Although some increases in abundance have occurred in some areas, levels for Northern and Spotted Wolffish in the Northwest Atlantic Fisheries Organization (NAFO) Div. 2J3K, where the majority of both populations resided, remain low relative to historic values. Due to an overall reduction in fishing effort since the 1990s, and mandatory release of both Northern Wolffish and Spotted Wolffish since 2003, mortality due to fishing of these two species has been reduced in Canada's Exclusive Economic Zone (EEZ). Proposed interim recovery targets consistent with Fisheries and Oceans Canada's (DFO) Precautionary Approach Framework were proposed but rejected based on concerns related to survey gear conversion factors. Further research should be conducted to determine a method of combining survey time series. The current levels of Canadian fisheries observer coverage in three major trawl fisheries in Newfoundland and Labrador (Greenland Halibut; Yellowtail Flounder; offshore Northern Shrimp) are adequate and effective in the determination of harm on wolffish, where they are a common bycatch species. Observer coverage could not be evaluated in other fisheries due to the lack of appropriate data. The maximum allowable harm that these species can sustain (while not jeopardizing their survival or recovery) could not be adequately quantified due to limitations in population modeling and uncertainty of their population dynamics. However, given levels of harm that occurred over the past decade, the decline in wolffish abundance has not continued, and has reversed in many areas, which suggests that the current harm is sustainable assuming that future stock productivity is similar to that observed in recent time periods.

Department of Fisheries and Oceans, Canada. (2013). Proceedings of the zonal peer review meeting of a current assessment of Northern, Spotted, and Atlantic Wolffish related to population status, life history, and habitat. Paper presented at the Zonal peer review meeting of a current assessment of Northern, Spotted, and Atlantic Wolffish related to population status, life history, and habitat;, St. John's, NL. http://waves-vagues.dfo-mpo.gc.ca/Library/359457.pdf

The most recent information on trends in abundance and distribution of Anarhichus denticulatus (Northern Wolffish), A. minor (Spotted Wolffish), and A. lupus (Atlantic Wolffish) was presented for Northwest Atlantic waters adjacent to Newfoundland and Labrador. All three species of wolffish were previously listed on Schedule 1 of SARA as being either threatened (A. denticulatus, A. minor) or of special concern (A. lupus), due to significant declines in relative abundance indices and reductions in area occupied during the 1980s and early 1990s. Their SARA statuses were upheld by COSEWIC in November 2012. However, some signs of population recovery were recently detected: primarily, indices of relative abundance and distribution for these species tended to increase in most areas surveyed during the last decade. All three wolffish species continue to reach their highest densities and cover their largest areas on the northeast Newfoundland and southern Labrador shelves. An area north of the Grand Banks represents the most persistent concentrations of Northern Wolffish and Spotted Wolffish in the Northwest Atlantic; while an area of persistent concentration for Atlantic Wolffish is the 1 southern Grand Banks. Recent catch rates, in both fall and spring surveys, continue to show generally stable or very gradually increasing trends. Similarly, the indices for area of occupancy were stable or increased slightly as the distribution of wolffish expanded.

Keith, C. (2006). Atlantic wolffish (Anarhichas lupus). Status of Fishery Resources off the Northeastern US. Retrieved from https://www.nefsc.noaa.gov/sos/spsyn/og/wolf/

Wolffish are taken primarily as bycatch in the Georges Bank Gulf of Maine otter trawl fisheries. During 2001 to 2005 otter trawl gear accounted for 75% to 98% of the wolffish landings, with gill nets and longlines accounting for almost all of the remaining landings. Total USA commercial landings of Atlantic wolffish increased from 270 metric tons (mt) in 1970 to near 1,200 mt in 1983, but subsequently have continuously declined and reached a recent low of 118 mt in 2005.

Historical: Since Atlantic wolffish have not been a commercially desired fish in the U.S. market and have only been captured as bycatch, there is a dearth of information about the historical Atlantic wolfish fishery. It does not appear that note has been made of its population prior to the 1970s.

Section IV: Management

Grant, S. M., & Hiscock, W. (2014). Post-capture survival of Atlantic wolffish (Anarhichas lupus) captured by bottom otter trawl: Can live release programs contribute to the recovery of species at risk? Fisheries Research, 151, 169-176. http://dx.doi.org/10.1016/j.fishres.2013.11.003

In 2003, the Atlantic wolffish (Anarhichas lupus), spotted wolffish (A. minor), and northern wolffish (A. denticulatus) were placed on Schedule 1 of Canada's Species at Risk Act which afforded them protection against harm. Consequently, it is mandatory to release both northern and spotted wolffish and it has been recommended that live-release protocols also apply to Atlantic wolffish. Catches in trawls comprise a significant threat to recovery of all three wolffish species and the Grand Bank yellowtail flounder (Limanda ferruginea) otter trawl fishery overlaps the most persistent high concentrations of Atlantic wolffish in the western North Atlantic. As a result, the trawl fishery initiated a voluntary live-release program. The current study investigated the post-capture survival of Atlantic wolffish captured incidentally in the Grand Bank yellowtail flounder otter trawl fishery. Short-term survival was monitored for wolffish placed in holding tanks onboard commercial vessels as well as wolffish returned to the ocean floor in cages. High (92-100%) post-capture survival was demonstrated in Atlantic wolffish following net entrainment in commercial tows up to 2.5 h, haul back through a thermocline (range, 5.8 degrees C), and exposure to 5-13 degrees C air temperatures for up to 2 h. High post-capture survival and similarities among all three species of wolffish with regard to morphology, physiology, post-capture activity levels, and tag returns in previous studies suggest live-release programs will help to rebuild populations of all three wolffish species. From a conservation perspective, release of wolffish can only be effective if it does not interfere with reproduction. Uncertainties with regard to the reproductive success of egg guarding male wolffish when returned to the ocean are discussed.

Blanchard K., Dawe J., Wall R. (2014) Stewardship and the Recovery of Threatened Wolffish in Eastern Canadian Waters. In: Urquhart J., Acott T., Symes D., Zhao M. (eds) Social Issues in Sustainable Fisheries Management. MARE Publication Series, vol 9. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-7911-2_6

Stewardship can be an effective strategy for the recovery of endangered and threatened species and as such it is one of the main implementation strategies under Canada's program for the recovery of species at risk. Stewardship involves both ethic and action but not all programs that are labeled as stewardship address both aspects. The case involving three species of wolffish in Newfoundland and Labrador demonstrates the effectiveness of using stewardship, combined with regulation, in order to achieve widespread adoption of new behaviours within a target audience. The conservation objective was to reduce mortality of wolffish caught as bycatch in many commercial fisheries, through techniques of live release. Results from a survey of fish harvesters over five years demonstrate that harvesters adopted the new behaviour, even though at first many did not agree with the protection afforded wolffish under the new *Species at Risk Act*. Evidence suggests that the change in behaviour was motivated more by legal and economic factors than by a stewardship ethic of environmental responsibility. Methods are described for encouraging that ethic and for building stronger, more positive relationships with fish harvesters as partners in recovery.

Dawe, J., & Schneider, D. (2014). Consilient knowledge in fisheries a case study of three species of wolffish (Anarhichadidae) listed under the Canadian Species at Risk Act. Ecology and Society, 19(3). http://dx.doi.org/10.5751/ES-06674-190326

Three species of wolffish have been listed under Canada's Species at Risk Act with consequences for commercial fisheries. Because harvester based local ecological knowledge (LEK) and science knowledge differ in goals, spatial and temporal scale, and mode of generalization, the current system struggles with including LEK along with traditional assessments in species at risk (SARA) processes. The differences in LEK and science led us to consider the concept of consilience in the sense of strengthened inductive knowledge via convergence or concordance of evidence from disparate sources. We used three criteria when considering consilience: a general concurrence of data, presence of unexplained inconsistencies, and a degree of complementarity between two disparate sources. Using wolffish in the northern Gulf of St. Lawrence we examined the feasibility of applying these criteria to two disparate sources of information: scientific stock assessments and data from structured fish harvester local ecological knowledge (LEK) interviews. We found that for wolffish there was consistency in observed trends and locations of high wolffish catch rates from both harvester LEK interviews and fishery-independent survey data. There was inconsistency between observed variability in catch sizes in harvester interviews and stock assessment maps. The science and LEK evidence were complementary in that observations took place at different spatial and temporal scales. They were complementary in that LEK was inshore, compared to science data from offshore. The explicit criteria we developed permit use of fishers' knowledge that, in the past, has often been discounted to zero, often thereby reducing trust by harvesters in the results of species at risk assessments. The concept of consilience shifts the focus from controversy to dialogue in the use of evidence and, so, is important in rebuilding marine fishing communities.

Dawe, J. L., & Neis, B. (2012). Species at risk in Canada: Lessons learned from the listing of three species of wolffish. Marine Policy, 36(2), 405-413. https://doi.org/10.1016/j.marpol.2011.06.010

The Canadian Species at Risk Act (SARA) was implemented in 2003. Since 2003, no fully marine Atlantic Canadian fish species has been listed and some observers are seriously questioning the extent to which SARA is effectively protecting marine fish species. Three species of wolffish found in North Atlantic waters were placed onto the SARA list in 2003 when it was implemented. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) originally listed these species in 2000 and 2001. The COSEWIC listings were based on catch-rate trends over large spatial scales from a relatively short time series of offshore research vessel survey data and status reports derived from research for an honours thesis. This case study of the wolffish listings draws on results from semi-structured interviews with key informants familiar with the listing and post-listing events, an analysis of existing documents and research on the SARA process, and on data from wolffish-focused Local Ecological Knowledge (LEK) interviews with commercial fish harvesters in the Northern Gulf of St. Lawrence. The results shed light on the wolffish listing process including perceptions of how the implementation of SARA has affected the process and prospects for listing fully marine species. The post-SARA listing developments in relation to wolffish, including harvesters' views about the listing are also explored. The results indicate mixed views about the benefits and problems associated with the requirement for public consultations and incorporation of stakeholder knowledge into the listing process under SARA. There is some evidence that the wolffish listing process has increased harvester stewardship and engagement and benefitted from their input into the safe release of wolffish. Finally, little attention has been paid by any of the stakeholder groups consulted to the potential future delisting of wolffish, arguably the most important goal of species conservation initiatives. Without delisting requirements or timelines set out in a species recovery plan it is impossible to establish concrete guidelines for recovery.

Kulka, D., C. Hood and J. Huntington. (2007). Recovery Strategy for Northern Wolffish (Anarhichas denticulatus) and Spotted Wolffish (Anarhichas minor), and Management Plan for Atlantic Wolffish (Anarhichas lupus) in Canada. Fisheries and Oceans Canada: Newfoundland and Labrador Region. St. John's, NL. x + 103 pp. http://publications.gc.ca/pub?id=9.563590&sl=0

Four species of wolffish (family Anarhichadidae) inhabit Canadian waters: Anarhichas denticulatus (northern), A. minor (spotted) and A. lupus (Atlantic) in the Atlantic and Arctic Oceans, and A. orientalis in the Arctic Ocean only. In May 2001, A. denticulatus and A. minor were assessed by COSEWIC (Committee on the Status of Endangered Wildlife in Canada) as "threatened" due to declines in their abundance and biomass. This assessment applies to species likely to become "endangered" if limiting factors are not reversed, while "endangered" refers to species facing imminent extirpation or extinction. COSEWIC indicated that over three generations the abundance of these two species had declined by over 90% and extent of distribution had decreased. Specific threats identified by COSEWIC included bycatch mortality in commercial fisheries and habitat alteration by trawling gear. A third species, A. lupus, was assessed by COSEWIC as "special concern", suggesting that it is particularly sensitive to human activities or natural events but is not endangered or threatened at this time. All three wolffish species where included in Schedule 1 of the Species at Risk Act (SARA) at the time of the Act's proclamation in June 2003.