Atlantic wolffish, *Anarhichas lupus*
Background

The Atlantic wolffish is an arctic to temperate marine species of the eastern and western North Atlantic. On the western side it ranges northward to 73°N off western Greenland (http://marvdc.bio.dfo.ca/pls/vdc/mwmfdweb.auth), and 64°35'N off Baffin Island (http://www.iobis.org/Welcome.htm). The southern limit of wolffish is 39°N (http://www.st.nmfs.gov/st1/commercial/landings/annual_landings.html). The species is demersal, sedentary, and solitary, feeds on benthic fauna, and prefers rocky bottoms at depths of one to 500 meters or more (Froese and Pauly 2005, Rountree 2002. After mating, eggs are deposited in masses on the sea bottom where they are guarded by the males (Keats *et al.* 1985). There is controversy over the spawning season (Rountree 2002), which is from August to October in Nova Scotia waters (Keats *et al.* 1985). The eggs incubate for three or more months depending on temperature. Larvae hatch in an advanced developmental stage, with only a small remnant of yolk remaining. For a period of one to two months (Pavlov 1986) they are considered to be pelagic, and have been taken in surface waters (Pavlov and Novikov 1993); with transition to the juvenile stage individuals spend increasing time on the bottom, mostly in deeper waters (Rountree 2002 and references therein). Rountree (2002) reviewed wolffish movements. Throughout their range wolffish migrations have been found to range from nonexistent to quite regular seasonally, and occasional individuals have migrated several hundred kilometres. In the western Atlantic parts of populations may move inshore for late summer spawning and depart in late fall after eggs hatch, while others spawn in deeper waters. White Sea wolffish regularly migrate along the shore line during the summer feeding season, and mature fish leave inshore feeding areas, where water temperatures apparently are too high for normal development of spawned eggs, to offshore spawning grounds with cooler waters (Pavlov and Novikov 1993). Atlantic wolffish appear to comprise discrete populations.

Atlantic wolffish has been fished commercially from 73°N off western Greenland (http://marvdc.bio.dfo.ca/pls/vdc/mwmfdweb.auth) and 56°23'N off Canada (http://marvdc.bio.dfo.ca/pls/vdc/mwmfdweb.auth) to its southern limit in New Jersey (http://www.st.nmfs.gov/st1/commercial/landings/annual_landings.html). The wolffish has been taken as bycatch off Newfoundland and Labrador (http://marvdc.bio.dfo.ca/pls/vdc/mwmfdweb.auth), and in the U.S. fishery. Stocks are not fished directly or actively managed. The U.S. recreational catch is insignificant (http://www.nefsc.noaa.gov/sos/spsyn/og/wolf/). In November 2000 the Committee on the Status of Endangered Wildlife in Canada listed the Atlantic wolffish as Special Concern, which is also its status under the Species at Risk Act. There has been much interest in this species as a candidate for cold-water aquaculture because of favourable aspects of its life history and biology (Brown 1998, Le François *et al.* 2002).

Temperature limits, critical thresholds, vulnerability, and barriers to adaptation

Sea surface temperatures in the current distribution of the Atlantic wolffish range from a February minimum of -2.1°C to an August maximum of 24.9°C.

Atlantic wolffish is a cold water species. Albikovskaya (1982) recorded catches in Newfoundland waters at bottom temperatures between -1.9°C and -1.5°C to 9°C, with catches low below 4°C. Scotian Shelf summer research surveys caught wolffish at bottom temperatures of 0-13°C, with a preference of 3-6°C (Scott 1983). Rountree (2002) summarized temperature data from both sides of the Atlantic. The thermal limits of Atlantic wolffish reflect its cold water distribution. Reproductive temperatures are: ovarian egg development less than 10-14°C, optimal at 5-7°C; ovulation less than 7°C; spawning in the northwest Atlantic August to October (when water temperatures are at their maximum); normal development of spawned eggs 3-12.8°C in experiments (higher temperatures result in abnormal embryos, and hatching is reduced above 7°C), 2.5-8°C in the northwest Atlantic; and hatching in the northwest Atlantic mostly in spring, but as early as October to December, all when temperatures are below maximum (Keats *et al.* 1985, Keats *et al.* 1986, Pavlov and Moksness 1994, Pavlov and Moksness 1996, Pavlov and Moksness 1997 and references therein, Pavlov and Novikov 1993 and references therein, Rountree 2002 and references therein, and Tveiten *et al.* 2001). Growth temperatures (in the northeast Atlantic) are: 9°C the upper limit for normal development of larvae, with higher temperatures causing morphological anomalies (Pavlov and Moksness 1995), 11-14°C the maximum for larvae (McCarthy *et al.* 1998), and 9-11°C the maximum for juveniles (McCarthy *et al.* 1999). The optimum reported for growth of Atlantic wolffish is 10-11°C or less (McCarthy *et al.* 1998, 1999; Moksness and Stefanussen 1990).

Atlantic wolffish ranked as one of the more sensitive fish species to global warming examined in this study, largely due to its lack of mobility, hence dispersal, in the egg and recently hatched stages. Thermally, the most critical stage in Atlantic wolffish life history is immediately before and after hatching of the eggs, where the upper thermal limit for successful hatching drops (to 7-8°C in eastern North Atlantic experiments); at earlier and later stages the eggs and larvae are less affected by temperature (Pavlov and Moksness 1994). However, from a climate change perspective the planktonic late larval/early juvenile stage may be the most vulnerable where surface water temperatures exceed 9-11°C.

Impacts

A 4°C rise in global temperature will impact the future distribution of Atlantic wolffish in the western Atlantic. Results from all models and scenarios are generally similar and show a potential loss of habitat in waters to the south of Cape Cod. The CCSR model also shows loss of habitat in Labrador waters.

The contribution of wolffish to fisheries bycatch in those waters will be lost. No northward gain of habitat is predicted in our study, which does not extend to the northern limit of Atlantic wolffish. All other waters generally will remain suitable for Atlantic wolffish.

Atlantic wolffish may be adaptable to increasing water temperatures resulting from global warming by slowly shifting their distribution to remain in suitable temperatures. This appears possible because of their life history, mobility, and the presence of appropriate habitat where water temperatures will remain suitable. However, predicting inter-population dynamics and consequences resulting from shifting distributions in response to global warming is beyond the scope of this project.

If Atlantic wolffish successfully shift their distribution to maintain environmental temperature while accommodating other ecosystem factors, they will see no increase in growth rate and will reproduce successfully. But if warmer temperatures are experienced they will stimulate an increase in the rates of growth and other functions where temperatures do not become excessive. Atlantic wolffish will be most vulnerable to temperature changes associated with global warming during the planktonic larval and early juvenile stages, from approximately February to March or April. There should be no detrimental effects in shelf waters of Labrador, Newfoundland, or Nova Scotia. In most models the Gulf of St. Lawrence surface waters warm appreciably, but should not approach critical thresholds of 9-11^{o}C for growth and survival of wolffish early life history stages. Surface waters from the Gulf of Maine southward will warm to a lesser extent, but if they approach or exceed the critical thresholds for larval growth in late spring the result could be morhphological anomalies.

A shift in wolffish distribution may not change the impact of at least one pathogen. *Aeromonas salmonicida*, the causative bacterium of furunculosis in fishes, occurs in Atlantic wolffish (Rodger *et al.* 1997). Though *in vitro* optimal growth for this pathogen occurs at approximately 20^{o}C, the species is considered to be psychrophilic (Guérin-Faublée *et al.* 1997). Experimental studies with salmonids have shown *A. salmonicida* mortality to be low or zero at 4-9^{o}C, moderate at 12-15^{o}C and high at 18-21^{o}C (Fryer *et al*. 1976). Since Atlantic wolffish prefer temperatures of 6^{o}C or less in the western Atlantic, *A. salmonicida* mortality at these temperatures would remain unchanged. However, should wolffish experience warmer temperatures the incidence of furunculosis in these individuals may be reduced.