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Temperature and Catchability

by

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Abstract

No direct empirical evidence has ever been produced to show that water temperature actually affects trawl catchability. Laboratory studies have provided some insight into the relationship between swimming endurance and temperature although no unifying trend has been revealed. Several *in situ* studies have measured the swimming speed and endurance of fish during trawl capture, but efforts to replicate tows across different bottom temperatures have been completely lacking. Attempts to tease temperature-dependent catchability effects out of groundfish survey data have given mixed results and interpretation.

Introduction

Variation in survey trawl catchability is known to be associated with changes in the vulnerability of fish to capture. Vulnerability is defined as the likelihood of capture once the fish are in the path of the trawl and is largely determined by the behaviour and swimming capability of fish (Gunderson, 1993; He, 1993; Wardle, 1993). Most assessment models that use indices of abundance from survey data assume that catchability and the relative availability and vulnerability of various age classes to the survey gear remain constant over time. Availability refers to changes in the proportion of the fish accessible to the zone of influence of the trawl. Spatial and temporal changes in environmental factors within the survey area can cause fish to aggregate in areas that are untrawlable or to be off bottom at certain times of the day and inaccessible to the fishing gear. In bottom trawl surveys, 'year effects' are common whereby there is a sudden increase or decrease in the abundance of most age classes in one year compared with estimates in neighbouring years. The assumption here is that there has been a change in catchability i.e., a change in either vulnerability or availability (distribution) due to a change in temperature (Smith and Page, 1996) or stock density (Godø *et al*., 1999; Swain *et al*., 2000). In this paper we review and summarize the current state of knowledge regarding the role of water temperature on swimming capability of fish in relation to trawl catchability.

Swimming Endurance Studies

Laboratory studies investigating the swimming endurance of fish have provided perhaps the best insight into the role of water temperature on trawl catchability. These studies measure the time to fatigue, i.e. endurance, using the 'fixed-velocity' method (Brett, 1967) and have direct application to trawl capture (Wardle, 1993). In general, a rise in water temperature typically produces an increase in both achievable swimming speed and endurance. With this, comes a shift in the maximum sustained speed (U_{ms}) as shown in Fig. 1. Swimming endurance studies conducted for commercially harvested marine species are compiled in Table 1 along with available estimates of U_{ms}.

For gadoids, the effect of temperature has not been consistently detected among studies and may be stock-dependent. Beamish (1966) reported that cod (*Gadus morhua*) from the Bay of Fundy region exhibited decreased swimming endurance at 5°C compared to 8°C. In re-examining Beamish's (1966) data, He (1991) estimated the U_{ms} of these cod to be 0.75 m/s at 5°C and 0.90 m/s at 8°C. He (1991) also measured the swimming endurance of cod from the Newfoundland region and found they exhibited reduced swimming endurance in comparison with Beamish's results, with a U_{ms} of 0.42 m/s at temperatures from -0.3 to 1.4°C. However, Winger *et al*. (2000) tested Newfoundland cod across a wider temperature regime (0.0-9.8°C) and were unable to detect a temperature-effect. Winger *et al*. speculated that the maintenance of swimming endurance at high and low temperatures may have been the result of thermal acclimation. Haddock (*Melanogrammus aeglefinus*), is the only other gadoid for which results have been published. Chandler (1967) tested haddock from the Bay of Fundy region and found a consistent increase in swimming endurance with increasing temperature across a range of temperature treatments of 1.5, 5.0, 8.5, and 10.5°C.

For flatfish species, the effect of temperature appears to be species-specific. Beamish (1966) reported, mixed results for winter flounder (*Pseudopleuronectes americanus*). The author reported increased endurance at 14°C, but found no consistent trend across the lower temperature treatments of 5.0, 8.0, and 11.0°C. Hashimoto *et al*. (1996) reported similar results for bastard halibut (*Paralichthys olivaceus*) in which increased endurance was observed for the 18.5-19.4°C treatment, but no discernable difference was found between the lower 6.3-7.7°C and 13.5-15.8°C treatments. By comparison, Winger *et al*. (1999) reported a significant increase in the endurance of American plaice (*Hippoglossoides platessoides*) with increasing temperature over a range of -0.2 to 9.7°C. Using failure time analysis to model the data, Winger *et al*. concluded that the herding efficiency of plaice by trawl sweeps in the zone ahead of the wing ends may be temperature-dependent (Fig. 2).

For redfish species, the only available information to date has been collected for *Sebastes marinus* by Beamish (1966). The author reported no appreciable difference in endurance between 5 and 8°C treatments, however a significant increase was observed at 11°C, wherein the fish were capable to swimming continuously at the lower speeds (i.e. within sustainable limits).

In Situ Studies

In situ observations of fish behaviour near bottom trawls have been collected for a number of marine groundfish species over the past few decades. The advance of technology and ingenuity of researchers during this period has lead to a number of techniques and instruments for both direct and indirect observation of fish during capture. This evolution has been documented in various reviews over the years (e.g. Parrish, 1969; Wardle, 1988; Urquhart and Stewart, 1993).

Empirical estimates of the swimming speed and endurance of fish during trawl capture have been quantified in several studies. In brief, these studies have been conducted using: visual observation (Kortokov, 1970; Hemmings, 1973); underwater television and video recordings (Main and Sangster, 1981, 1983; Castro *et al*., 1992; Bublitz, 1996; Kim, 1996; Glass *et al*., 1999); acoustic transponding tags (Harden Jones *et al*., 1977); acoustic telemetry (Engås *et al*., 1998); and, most recently, split-beam acoustics (Godø *et al*., 1999b). Despite the number of studies thus far, none have directly investigated the effect of water temperature on the swimming capability of fish during capture. To date, the only available evidence of possible temperature-dependent catchability has been reported by Inoue *et al*. (1993). The authors reported a weak swimming response of adult walleye pollock (*Theragra chalcogramma*) at bottom temperatures of 0.5 and 2.0°C using towing speeds of 1.8 to 2.0 m/s. Although the authors attributed the behaviour to low temperatures, the finding is not conclusive as comparative observations were not made at warmer temperatures nor was swimming capability directly quantified.

In situ studies continue to provide the most promising avenue for future research into the role of water temperature on trawl catchability. The advent of acoustic techniques (Godø *et al*., 1999b) and infrared illumination for video (Olla *et al*., 2000) in particular, have mitigated many of the limitations (e.g. depth, light intensity), which faced early television and video observation techniques. Future studies should endeavor to replicate across seasons or experimental sites in order to assess temperature dependence, which unfortunately has been lacking in previous studies.

Analytical Studies

There has long been a debate among assessment scientists whether temporal and spatial changes in bottom temperature might affect the swimming capability of groundfish species and therefore the efficiency and selectivity of survey trawls. Bottom temperatures are expected to influence the spatial patterns of cod (Smith and Page, 1996), i.e. availability. Swain and Kramer (1995) showed that when cod are abundant they select for cold temperatures and at low levels of abundance they select warm temperatures. Bottom temperature is also assumed to influence swimming capability and hence catchability, i.e. vulnerability (He, 1993; Smith and Page, 1996). Both He (1993) and Smith and Page (1996) hypothesize that cod in colder water have reduced swimming speed and endurance which would result in increased catchability. Swain *et al*. (2000) concluded that although there were correlations between both temperature and abundance and distribution and abundance, it had a negligible effect on catchability. The authors concluded that density-dependent catchability was responsible for differences in abundance levels of cod in the southern Gulf of St. Lawrence. Colbourne and Bowering (2001) showed that the increase in abundance of yellowtail flounder (*Limanda ferruginea*) during the 1990s was associated with an increase in the bottom temperatures on the Grand Bank and speculated that high temperatures lead to an increase in catchability. Walsh *et al*. (2001) in analyzing the same data on yellowtail flounder concluded that the large increases in abundance was due to the increase herding efficiency of the new survey trawl (1995-2000) and high densities when compared with the old standard survey trawl (1990-1994) and low densities.

The debate around analysis of temperature effects on gadoid and flatfish catchability says that catchability increases at low temperatures (cod) or increases at high temperatures (yellowtail flounder). Both suggest a linear response, which indicates that as temperatures increase for cod then catchability decreases and as temperature decreases then catchability of yellowtail flounder decreases. The other side of the debate says that high densities of cod in cold water and high densities of yellowtail flounder in warm water produce high abundance estimates not related to temperature but due to density dependent catchability. Harley and Myers (2001) modeled known length-specific survey catchability for 47 fish stocks (cod and yellowtail flounder) using meta-analysis to estimate survey catchability. The authors reported higher catchability for surveys conducted in the summer-fall compared to those in the spring-winter, indicating a temperature effect but they did not account for the effect of density in their analysis.

Summary

The period of time that fish are capable of swimming at a given speed, i.e. endurance is critical to the herding and chasing processes of trawl capture. Laboratory studies have provided the only evidence of temperature-dependent swimming endurance, though no unifying trend has been revealed for gadoids or flatfish. *In situ* studies have the capability to provide direct empirical evidence of temperature-effects, though efforts have not been dedicated to this task. Indirect evidence for a temperature-catchability relationship from analytical approaches of survey data have also shown conflicting conclusions for the effect of temperature on catchability, often within the same species.

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Table 1. Laboratory studies investigating the swimming endurance of commercially harvested marine species.

Species	Temp. (°C)	FL (m)	Velocity (m/s)	U_{ms} (m/s)	Method of Estimating U_{ms}	Source*
Clupea harengus	13.5	0.23-0.30	1.03-1.37	1.03	direct measurement	1
Gadus morhua	5.0-8.0	0.35-0.37	0.75-1.35	-	-	2
Gadus morhua	-0.3-1.4	0.36-0.52	0.42-1.36	0.42-0.45	direct measurement	3
Gadus morhua	0.0-9.8	0.41-0.86	0.60-1.30	0.66	failure time analysis	4
Hippoglossoides platessoides	-0.2-9.7	0.14-0.44	0.30	-	-	5
Melanogrammus aeglefinus	1.5-10.5	0.32-0.38	0.44-1.41	-	-	6
Paralichthys olivaceus	6.3-19.4	0.05-0.36	0.07-0.52	-	-	7
Pollachius virens	14.4	0.23-0.50	0.83-1.70	0.88-1.12	direct measurement	1
Pseudopleuronectes americanus	5.0-14.0	0.19-0.23	0.75-1.35	-	-	2
Sardinops sagax	19.0	0.06	0.32-0.76	-	-	8
Scomber japonicus peruanus	19.0	0.10	0.30-0.80	-	-	8
Scomber scombrus	11.7	0.29-0.33	1.16-1.45	1.16	direct measurement	1
Sebastes marinus	5.0-11.0	0.16-0.19	0.52-1.35	-	-	2
Stenotomus chrysops	12.0	0.14-0.15	0.32-0.63	0.32	direct measurement	9
Trachurus japonicus	20.0	0.15-0.21	0.84-1.85	0.87-0.98	direct measurement	10
Trachurus symmetricus	18.5	0.09-0.18	0.38-1.60	0.94	probit analysis	11
Verasper moseri	17.0-17.6	0.13	0.19-0.42	-	-	7

* Sources: 1, He and Wardle (1988); 2, Beamish (1966); 3, He (1991); 4, Winger et al. (2000); 5, Winger et al. (1999); 6, Chandler (1967); 7, Hashimoto et al. (1996); 8, Beamish (1984); 9, DeAlteris and LaValley (1999); 10, Xu et al. (1994); 11, Hunter (1971).

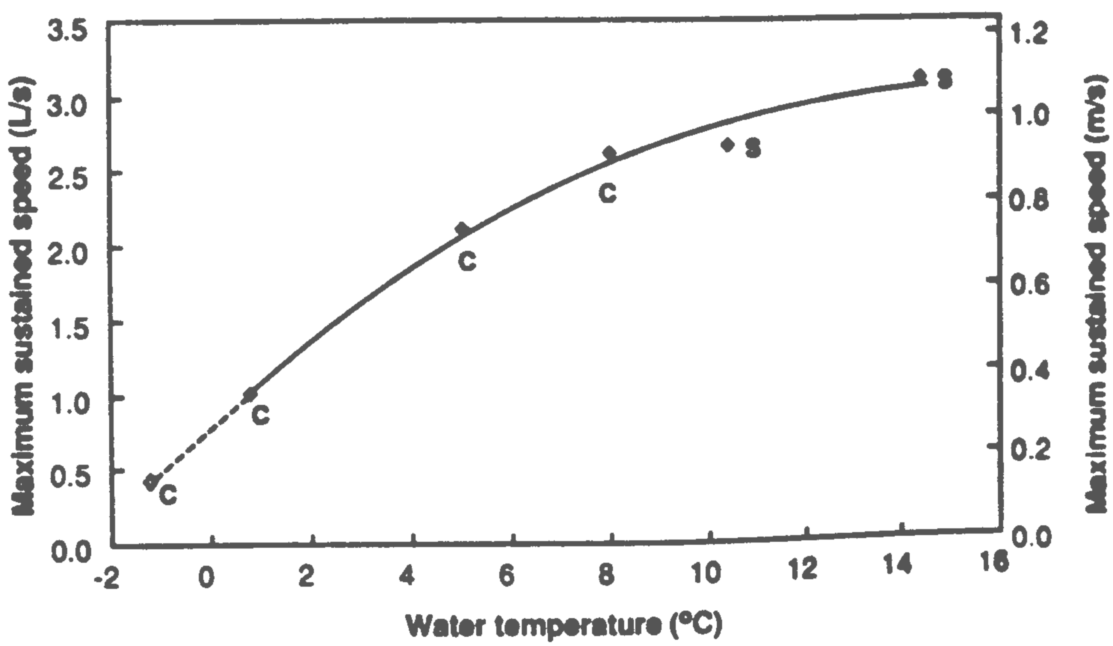

Fig. 1. Effect of water temperature on the maximum sustained speed (U_{ms}) of gadoid species (34-36 cm). Data presented are for Atlantic cod (c) and saithe (s). Adopted from He (1993).

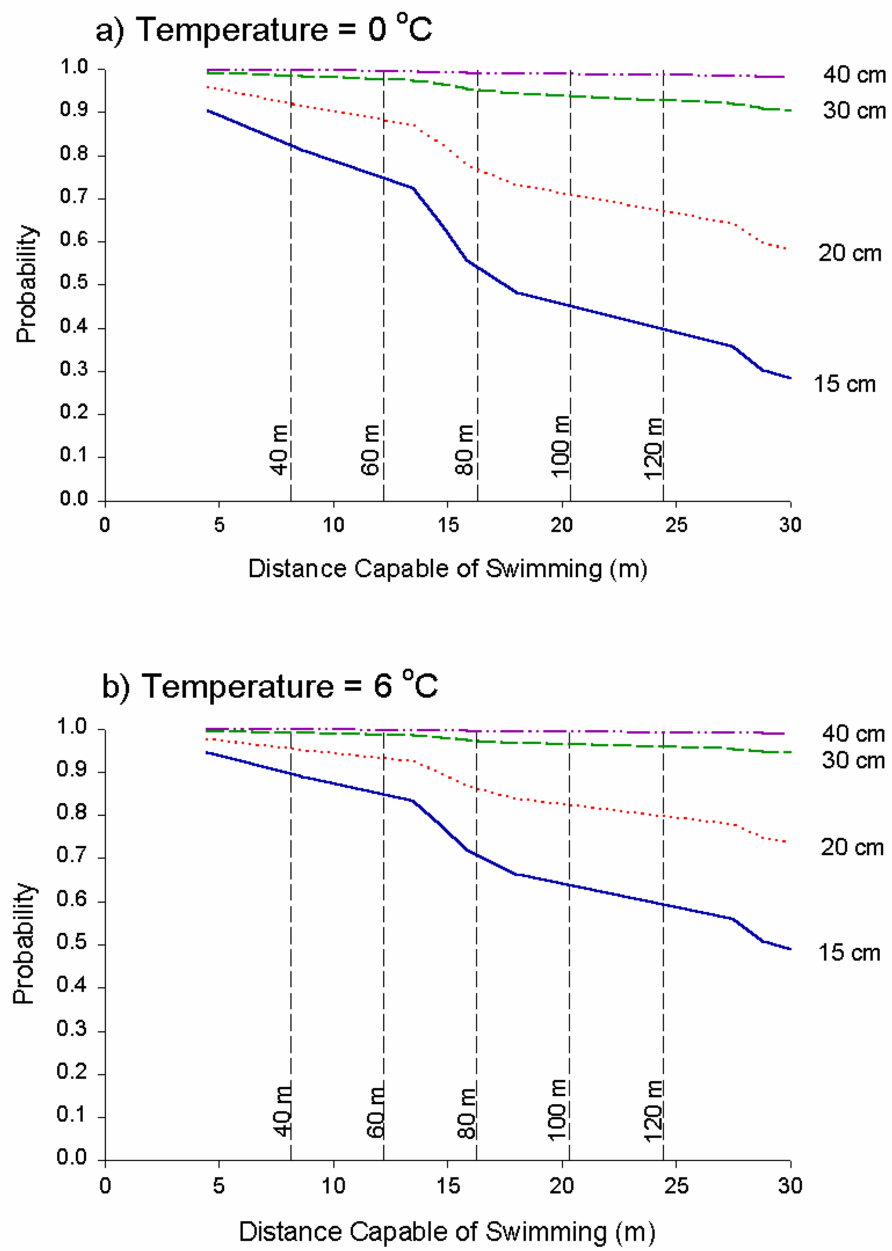

Fig. 2. Probability curves for distances capable of swimming (at 0.3 m/s) by American plaice of different fish lengths at a) 0^{o}C and b) 6^{o}C. The vertical dashed lines represent a bottom trawl with a herding speed of 0.3 m/s (e.g., sweep angle of 11.5^{o}, towing speed of 1.5 m/s) and indicate the distance the fish would be required to swim in order to successfully reach the trawl path after initially encountering the sweep. Corresponding probabilities of reaching the trawl path can be read from the y-axis.