Measuring Swimming Capacity of Yellowtail and Windowpane Flounders to Provide Scientific Knowledge for Reducing Their Bycatch in Scallop Dredges

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1.0 EXECUTIVE SUMMARY

Project Title: Measuring Swimming Capacity of Yellowtail and Windowpane Flounders to Provide Scientific Knowledge for Reducing Their Bycatch in Scallop Dredges

Year Awarded: July 1, 2017 – June 30, 2020

RSA Priorities Addressed by This Research: Highest Priority No. 2: "Bycatch research - Identification and evaluation of methods to reduce the impact of the scallop fishery with respect to bycatch, including gear modifications to reduce bycatch."

Yellowtail flounder (*Pleuronectes ferruginea*) and northern windowpane flounder (*Scophthalmus aquosus*) are currently listed as "overfished" in part due to high levels of non-target catch in the bottom trawl and sea scallop fisheries. Therefore, there is an urgent need for reducing bycatch of these important flounder species in the scallop and groundfish fisheries. The escape of flounders from sea scallop dredges is challenging due to the fast towing speeds used in the fishery, typically at 5 knots. Better understanding of the swimming ability of these species and how they react to approaching fishing gear may provide insight about their ability to escape from towed fishing gears, such as trawls and dredges. In this project, we intend to quantify some aspects of swimming physiology and behavior: swimming speed and fast-start behavior as they relate to water temperature, and to model how scallop may escape from an approaching dredge towed at different speeds. We predict fish's maximum swimming speed based on their fish physiology, specifically muscle contraction time. We measure contraction time of muscle at water temperatures from 5 to 25 °C. It was found that flounders, similar to roundfish, took much longer time to contract their lateral muscle at lower temperature, indicating that lower water temperatures greatly reduce fish's maximum swimming speed. The maximum swimming speed at 25 °C may be four times higher than that that at 5 °C. We have only some preliminary data on the fast-start characteristics of flounders in relation to water temperature. Limited data have also showed that flounders have much longer latency time at lower water temperatures. Simulation model with the data indicates that flounders of larger sizes and at higher water temperatures have great probability to escape from scallop dredges towed at lower towing speeds. Further understanding the physiology and behavior of fish, especially reaction time, will further help assess potential escape at different phases of the capture process and aid in modification to the design and operation of scallop dredges to reduce bycatch of flounders.

Industry Partners: This project does not have a field component; therefore, no industry vessels have been involved in research. However, F/V "Endurance" and F/V "Brittany Eryn" from New Bedford MA have been involved in compensation fishing.

2.0 PRELIMINARY RESULTS AND DISCUSSION

Project goals and objectives

The overarching goal of this proposed project is to measure the swimming capacity (swimming speed, acceleration and endurance) of yellowtail and windowpane flounders to provide the necessary knowledge for designing behavior-based bycatch reduction gears and strategies in the scallop dredge fishery in northeastern USA. These goals will be achieved through the following project activities:

1) Characterizing startle response of flounders when they are approached by a dredge in terms of reaction time, acceleration, speed and duration of the fast-start behavior.
2) Measuring swimming speed of yellowtail and windowpane flounder of different sizes at different water temperature.
3) Determining the maximum swimming speed of fish through measurements of the muscle contraction time of yellowtail and windowpane flounders.
4) Developing a model of fish reaction to scallop dredge based on startle response behavior and swimming capacity and incorporating environmental variables and recommending possible strategies for releasing flounder bycatch from the dredge.

Muscle contraction time and swimming speed

The maximum swimming speed of fish including flounders are difficult to measure, but it can be predicted from the muscle contraction time of fish's white muscle (Wardle, 1975). Wardle (1975) theorized that in order for fish to beat its tail once, the muscle on each side of fish needed to contract once. How fast the fish can contract its muscle limits the maximum tail beat frequency. Because the swimming speed is closely and linearly related to tail beat frequency, the maximum swimming speed of fish can be predicted from its maximum tail beat frequency as demonstrated in many species (Bainbridge, 1958; Wardle, 1975; 1980).

The muscle contraction time of windowpane flounder was measured with isolated muscle blocks (approximately 4 cm x 2 cm x 1 cm). The block was perfused with a saline isobath at temperature between 5 and 25 °C at 5 °C increments. The muscle was stimulated with a single electric pulse (2 µs @ 2V) to produce contractions which was recorded using a flex transducer (description in Riyanto et al., 2014). As the muscle contracts the two electrodes are moved towards one another resulting in the acrylic sheets bending. The flex of the acrylic is measured using a strain gauge and was amplified and recorded using a digital oscilloscope (Figure 1). The measured contraction times are used to calculate the theoretical maximum swimming speed (U_{max}, in m/s) with the following equation (Wardle, 1975): $U_{max} = \frac{S_L}{2\,T_c}\,L$, where S_L is the stride length (the distance moved forward in each tail beat in terms of body length L), and T_c is the muscle contraction time (in seconds). We use S_L = 0.7 for our calculation of U_{max}.

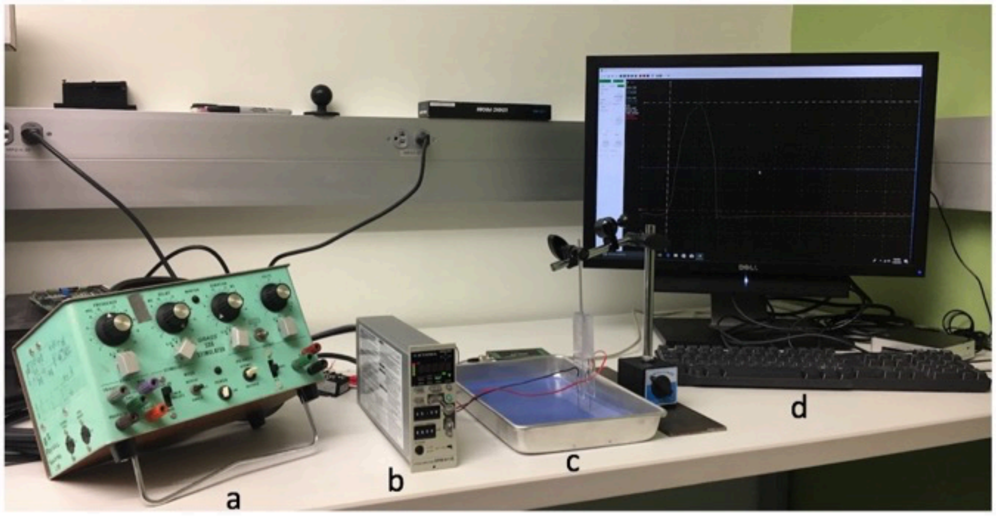

Figure 1. Setup for measuring contraction time of fish muscle. a – stimulator, b – amplifier, c – strain gauge and saline tray, d – recorder and display (computer and monitor).

Temperature and reaction time

The unique body morphology of flatfish allows them to rest on, or under, the seabed relying primarily on camouflage for predator avoidance. As a result, flounders are typically reluctant to flee until danger appears eminent. Once the fish attempt to escape, a complex series of maneuvers are orchestrated resulting in a burst of acceleration. This includes a push off the seafloor, rapid muscle contractions and opercular jetting (Brainerd et al. 1997, Webb 1981). This is typically referred to as fast-start behavior.

Characterization of the fast-start behavior includes measurements of reaction time, acceleration and velocity after a startling stimulus. In this study, individual fish were placed in a long narrow tank (120 cm L x 71 cm W x 30 cm H, Figure 2A) and allowed to acclimate for one hour. The tank was fit with two viewing windows for filming and a PVC pipe containing several holes to direct water flow toward the flounder. The tank features two removable partitions, which holds the fish in front of the viewing window during the acclimation period. Following acclimation, one of the partitions was removed, and an electric pulse stimulus (15V, 2 - 3A, 0.5 s) was applied, resulting an escape response.

The electric stimulus was applied through a series of copper wires buried under the sand in the test tank (Figure 2B). The stimulus was applied to the fish's tail by activating the electrode (copper wire) near the tail. An LED light was attached to the tank to signal when the shock was administered. The light was captured in the video, together with fish movement, to allow for accurate measurements of response time.

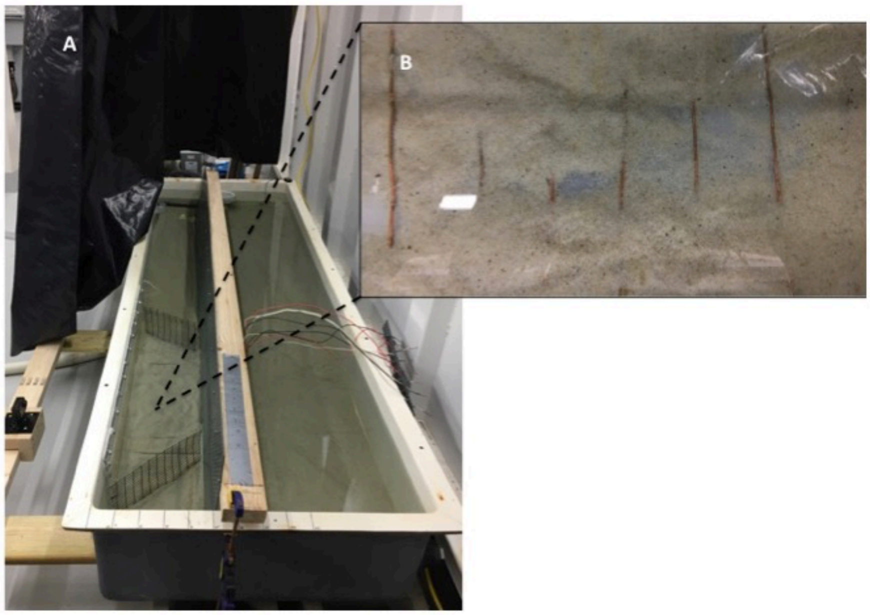

Figure 2. (A) Fast-start testing tank (120 cm L x 71 cm W x 30 cm H). (B) Electrical shock panel made of copper wiring partially buried under the sand.

The fast-start behavior is characterized by time and position measurements collected using high-speed videography. A GoPro Hero 3+ camera filming at 120 frames per second gives ~8 ms temporal resolution. The camera is calibrated using Python and OpenCV to remove lens distortion following the methods described by Bouget (2015) and Bradski and Kaehler (2008). Two-dimensional position measurements are obtained using the LoggerPro software package (Vernier). A calibration pattern was placed within the test tank at a range of distances from the camera to convert from pixel space to real-world coordinates (i.e. mm). The fish were tested up to three times at each test temperature (4, 8, 12, and 16 °C).

Modelling flounder escape from a scallop dredge

The objective of our modelling is to understand how gear and operational parameters (e.g. towing speed) affect the probability of flounder escaping from dredges and how this may be affected by environmental conditions, especially water temperature at bottom. We also hope that it will give insight into conditions with the potential to enhance probabilities of escape, for example, specific dredge areas where modifications would be effective for providing opportunities for flounders of different sizes and species to escape under different conditions.

Currently, only windowpane flounder muscle contraction times have been modeled, as the sample size of yellowtail flounder is too small to yield statistical power. Operational variables included the specifications of a standard New Bedford scallop dredge (4.6 m, or 15', wide dredge towed at 5 knots), which were used as a prototype for modeling and analysis. Input variables are shown in Table 1 and included fish body length, distance from the center of the dredge, distance in front of the dredge, escape angle, and temperature.

Table 1. Input variables, as well as physiological and operational variables in the escape probability model. Variable name, definition, treatments types, and units are shown.

Variable	Definition	Treatments	Units
Input variables			
wp_lengths	Body length of fish	10, 15, 20, 25, 30, 35	cm
dr_edge	Distance from center of dredge	0, 0.5, 1, 1.5, 2	m
dr_dist	Distance in front of dredge	1, 2, 3, 4, 5	m
angle	Angle of swimming	0, 15, 30, 45, 60, 75, 90	degrees
temps	Water temperature	5, 10, 15, 20, 25	°C
Behavioral variables			
stride_length	Forward movement in one tailbeat	0.7	body length
Operational variables			
tow_speed	Towing speed of dredge gear	2.57	m/s
dredge_width	Width of dredge	4.57	m

Raw muscle contraction data was plotted for diagnostic purposes, and then modeled using a GLMM, with observation (or fish ID number) as a random effect. Both body length and muscle location (blind side or eye side) were found to be insignificant and were therefore dropped from the model and the data was refit. After validating the model by examining residuals, prediction plots were created to calculate the mean and variance for each temperature treatment (5, 10, 15, 20, and 25 °C). Using this information, simulated random predictions of muscle contraction time were generated, and bootstrapped 100 times for each temperature. In the next version of the model, we will bootstrap the random predictions 1000 times for increased accuracy in our estimates of variability. The simulated predictions were then saved to be utilized in the escape probability model.

The escape probability model is based on the possible position of the fish when it reacts to the dredge and the direction of fish's escape attempt (Figure 3), considering fish size, water temperature and other variables in Table 1. In the escape probability model, the simulated muscle contraction times were imported for each temperature, and several variables were assigned (Table 1). An "escape parameter function" was created to calculate the required maximum swimming speed by first calculating the required escape distance, and then the required escape time. The distance required to escape the dredge path was calculated by converting degrees to radians, and using the following equation:

$$escape\ distance = \frac{\left(\frac{dredge\ width}{2}\right) - Distance\ from\ dredge\ edge}{\cos\left(escape\ angle\right)}$$

To calculate the required escape time, the distance of forward swimming (or x distance) was first calculated by multiplying the sine of the escape angle by the escape distance. Then the required escape time was calculated using the following equation:

$$escape\ time = \frac{x\ distance}{tow\ speed}$$

Using the values calculated above, the required maximum swimming speed was then estimated using the equation shown below:

$$required\ maximum\ speed = \frac{escape\ distance}{escape\ time}$$

The model then iterated through the simulated data for each temperature and length treatment. The data points generated from each temperature file are input, and theoretical maximum swimming speeds were calculated using the U_{max} equation from Wardle (1975). The model output was saved as a separate file, and input into a graphics module, where each node is drawn as a different length depending on the probability of flounder escape.

A conceptual schematic of these calculations is shown in Figure 3. Additionally, we assumed that fish swimming at an angle of 0° would never successfully escape the dredge path, as they would be swimming constantly in front of the dredge. If the fish's theoretical position was beyond edge of the dredge, they would not be confronted by the gear, and were not included in the model.

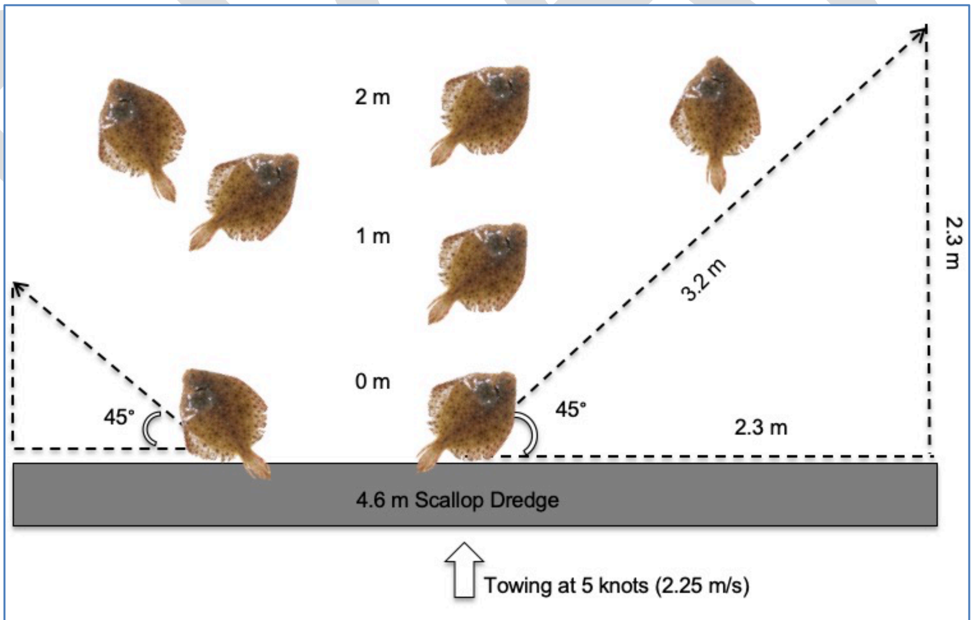

Figure 3. Theoretical explanation of escape probability model approach. Distance to escape is calculated using the known location of a theoretical flounder in relation to the dredge.

Preliminary results

The muscle twitch device has been tested on both the top (eyed side) and bottom (blind side) of 48 windowpane flounders. As hypothesized, preliminary results show decreased contraction times at increased temperatures, implying an increased maximum swimming speed (Figures 4 and 5). Initial results also suggest higher variability in muscle contraction measurements at low temperatures. So far, calculated maximum swimming speeds range from approximately 1.6 to 6.5 m/s depending on fish length and water temperature (Figure 5). Initial results suggest no significant difference in the muscle contraction times of eye and blind side muscle.

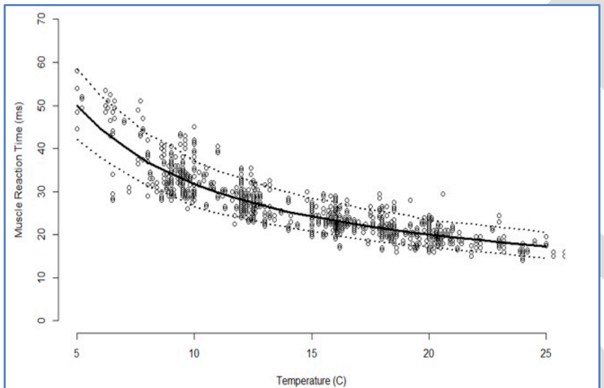

Figure 4. Results from GLMM showing muscle contraction time in relation to temperatures from 8-20C. 95% confidence intervals are shown in the dotted line.

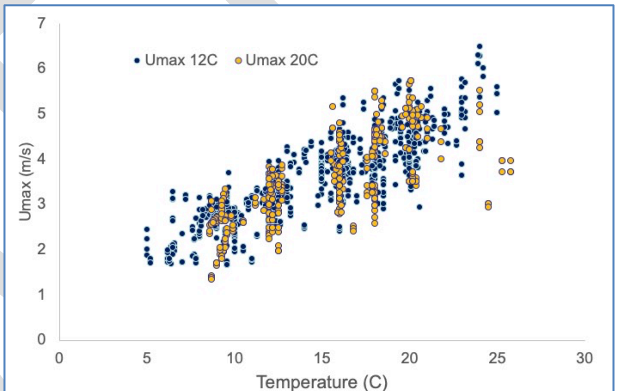

Figure 5. Preliminary results of theoretical maximum swimming speeds of windowpane flounder in relation to muscle temperature as calculated from muscle contraction time. Measurements are from fish acclimated to both 12 C (blue filled) and 20 C (orange filled).

Preliminary results suggest that windowpane flounder escape probability increases with water temperature and fish body length, and decreases with increasing tow speed of the dredge (Figures 6 and 7). The model output shows that theoretically, 1 m might not be enough of a head start for windowpane flounder. We hope that the addition of fast-start will strengthen the accuracy of the model.

3.0 SPECIAL COMMENTS

The special challenge for this project is to obtain sufficient number of fish that can be acclimated to laboratory conditions for physiological and behavioral studies.

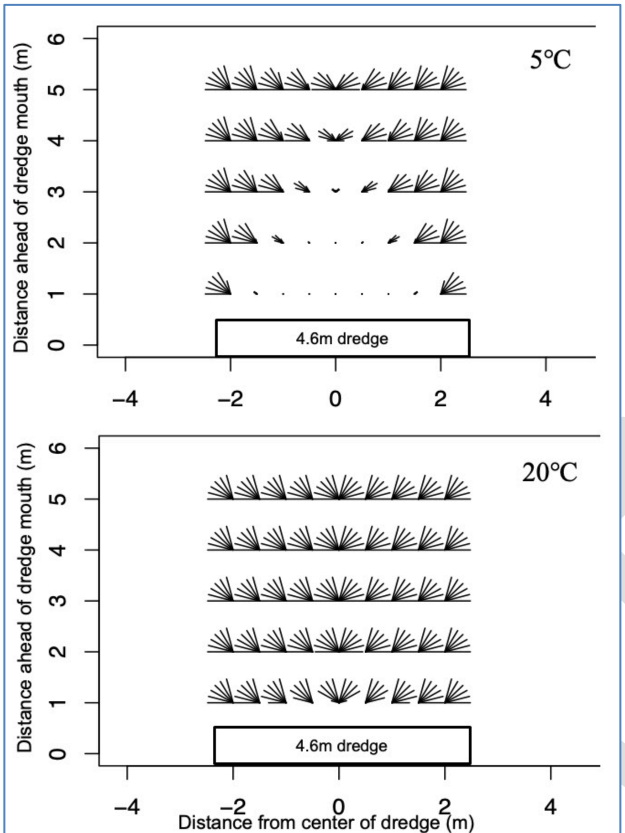

Figure 6. Effect of temperature on windowpane flounder escape probability. Lines represent angle of escape (from 0 - 75°) and length of line represents escape probability (0 - 100%)

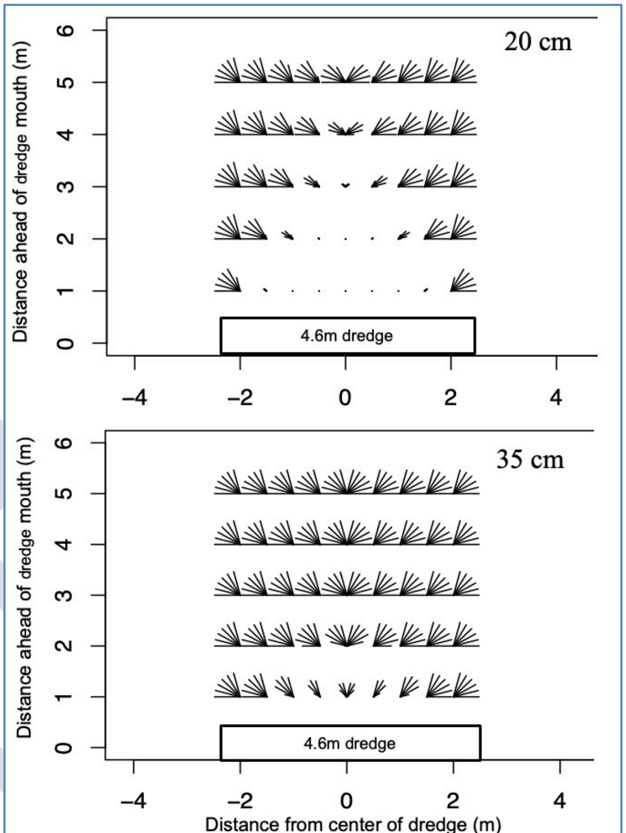

Figure 7. Effect of body length on windowpane flounder escape probability. Lines represent angle of escape (from 0-75°) and length of line represents escape probability (0-100%)

4.0 REFERENCES

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