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Manuscripts

1 **Migration diversity, spawning behavior and habitat utilization of Winter Flounder**

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15 **Abstract**

16 Winter Flounder have declined to less than 11% of their historical abundance in offshore
17 areas and have experienced severe declines and inbreeding in coastal subpopulations.
18 Understanding metapopulation structure and disparate migratory behavior is vital to
19 understanding the species' dynamics in the region. We used acoustic telemetry to evaluate
20 migratory types, homing and spawning behavior in adult Winter Flounder (n=72) in Mattituck
21 Creek, NY. Telemetry results showed 17% of the tagged individuals displayed resident behavior
22 and remained in the creek year-round despite average summer temperatures reaching 28°C.
23 Alternatively, the migratory group (~83%), started to leave the system when the average water
24 temperature reached 12°C. A dominant driver of migration was not indicated; instead, migration
25 out/into the creek appears complex and related date, temperature, lunar cycle, photoperiod and
26 year. Approximate spawning was estimated to occur as early as November and continued
27 through April based on aggregative behaviors of adults and back-calculations of dates using
28 otoliths. Our results support the emerging view that Winter Flounder's dynamics reflect local life
29 history and population diversity that is currently unaccounted for in management.

30 Introduction

31 Large-scale movements by individuals occur across almost all taxa (Dingle and Drake
32 2007). The prevalence of migration across taxa indicates it is a key life history component,
33 particularly of marine and freshwater fishes (Roff 1988; Secor 2015). Maximizing fitness in
34 heterogeneous environments has favored migrations related to foraging, spawning, selection of
35 thermal environments (Heape 1931), and resting (Hobson 1973; Ovidio et al. 2013). Movement
36 is driven by external stimuli such as chemical and temperature cues, water currents, light, and
37 population density gradients (Harden Jones 1968; Secor 2015; Frisk et al. 2014). Populations
38 often display migratory contingents (Gross 1985; Kraus and Secor 2004; Secor 2015) and in
39 some cases meta-populations may overlap spatially and display differing migratory patterns
40 (Frisk et al. 2014). For example, populations of Winter Flounder (*Pseudopleuronectes*
41 *americanus*) exhibit migration diversity (Sagarese and Frisk 2011) and fine-scale population
42 structuring (O’Leary et al. 2013) which suggests migration is a key life history attribute of this
43 species.

44 Winter Flounder are so named because of their annual spawning migrations to nearshore
45 coastal habitats in the winter (Wuenschel et al. 2009; DeCelles and Cadrin 2010; Wilber et al.
46 2013). The timing of the nearshore movements varies with location, and many studies have
47 found that Winter Flounder display natal homing to spawning grounds (Saila 1961; McCracken
48 1963; Phelan 1992). Historically, two groups of Winter Flounder have been observed in the New
49 York Bight region: a migratory group which reside in deeper waters for the majority of the year,
50 then move to inshore waters to spawn, returning offshore when the water temperatures start to
51 increase (Lobell 1939; Perlmutter 1947; Sagarese and Frisk 2011), and a resident group which
52 resides in the coastal bays for the majority of the year and exhibit limited movement to deeper

inshore waters during high temperatures (McCracken 1963; Howe and Coates 1975; Phelan 1992). Both groups are thought to be present in estuaries to spawn from January through May (Klein-MacPhee 2002). It remains unclear whether resident Winter Flounder represent contingents originating from the same genetic population or whether Winter Flounder have local population structure with differing migratory behaviors (O’Leary et al. 2013; Frisk et al. 2014). Additionally, while historic studies recognized life history diversity, recent analysis of stock structure have not reported local structure or migration diversity (McBride 2014) and are not considered in the assessment process (NEFSC 2011).

The offshore migrations by Winter Flounder have been observed during increasing springtime temperatures (McCracken 1963; Scarlett and Schneider 1988). However, a wide range of environmental variables have not been evaluated as potential drivers triggering offshore migration. Capossela et al. (2013) showed that temperature and photoperiod were significant predictors in Summer Flounder (*Paralichthys dentatus*) dispersal. Harden Jones (1980) suggested that North Sea Plaice (*Pleuronectes platessa*) begin their tidal transport spawning migration when the sunset, full moon, and low water slack all coincide. A more complete evaluation of potential migration triggers is needed to connect Winter Flounder movement patterns to the reproductive and environment drivers of habitat selection.

Winter Flounder have been harvested commercially and recreationally since the early 20th century (Perlmutter 1947). However, in the last twenty years spawner abundance has drastically declined (Manderson 2008; Socrates and Colvin 2010; Frisk et al. in prep.), and our understanding of spawning behavior and dynamics in the southern New England region is limited. On Long Island, NY, studies have shown that inbreeding of Winter Flounder occurs in multiple bays along the South shore (O’Leary et al. 2013) indicating a low number of spawning

adults. The regional stock structure of Winter Flounder has been studied (McBride 2014), but there remains uncertainty surrounding their broader ecology and local life history and migration diversity (Sagarese and Frisk 2011; Frisk et al. 2014; Yenko et al. 2015). The emerging information on stock and/or migratory diversity contradicts the historical views (Lobell 1939; Perlmutter 1947) which highlights the need for research into the population ecology of the species on a regional and local scale to support science based management.

This study used passive acoustic telemetry to investigate migration, spatial habitat use and spawning behavior of Winter Flounder in Mattituck Creek, a tidal estuary on the North shore of Long Island, New York. We explored the drivers of migration and within system habitat use of the estuary for both residents and migrants utilizing Generalized Linear Models. Further, temporal and spatial spawning dynamics were explored utilizing acoustic telemetry and otolith derived back-calculated spawning dates. Finally, migration diversity is compared to previous studies in the region to explore the broader life history of the species.

Methods

Study Site

Mattituck Creek is located in Suffolk County on Long Island, New York (40.99°N, 72.54°W). The tidal system connects to the Long Island Sound by Mattituck Inlet, which is stabilized with an artificial jetty (Figure 1). The mean tidal range in Mattituck Creek is 1.5 m (NOAA 2013). Side scan sonar was performed in Mattituck Creek in January 2017. The bathymetry is consistently between 0.6 and 1.8 meters with only one section of the creek briefly reaching 3.7 meters. The creek is characterized by soft substrate towards the back of the creek and closer towards the inlet the bottom type becomes harder.

98 **Collection of Winter Flounder**

99 Mature Winter Flounder were captured and tagged during a weekly trawl survey in
100 Mattituck Creek conducted between the months of March and June 2015, and December 2015 –
101 March 2016. Trawling was conducted aboard the 7.4 m R/V *Privateer* using a 2 m beam trawl
102 with a mesh size of 5 cm and a single tickler chain. Trawls were towed for 5 minutes at an
103 average speed of 1.3 m/s. The entire creek was sampled for adult Winter Flounder, and then
104 areas that provided the highest catches of adults were targeted for the remaining tows. Fish were
105 captured in the creek, with the majority of captures located in the back (south) section of the
106 creek by receivers 7-9 (Figure 1).

107 YOY Winter Flounder were captured and total length of each individual was measured to
108 the nearest mm in biweekly trawl surveys from May – September 2016. A 1 m beam trawl (6
109 mm mesh) was towed by the R/V *Privateer* for 5 minutes at an average speed of 1.2 m/s.
110 Mattituck Creek was divided into ten strata of equal area and a stratified sampling design was
111 utilized with one tow per strata with a random starting location in each stratum (Figure 1).

112 **In System Movements**

113 *Tagging of Adult Winter Flounder.* Over two years, a total of 89 adult Winter Flounder
114 were caught during 27 sampling days and 443 tows. Out of the 89 adults, 72 were tagged with
115 acoustic transmitters (30 in 2015 and 42 in 2016) (Table 1). Upon capture, total length was
116 measured to the nearest mm of all Winter Flounder and adults greater than 240 mm were
117 equipped with an acoustic transmitter (Model V9-2L, 69 kHz, 9 x 24 mm; VEMCO Ltd.). This
118 minimum size was chosen to ensure the Winter Flounder tagged were adults (Perlmutter 1947),
119 as well as to allow the acoustic transmitter to fit inside the individual. Each tag was programmed

to ping randomly every 80-160 seconds and had an estimated battery life of 802 days. The transmitter was surgically implanted into the peritoneal cavity of each Winter Flounder following Stony Brook University's Institutional Animal Care and Use Committee approved protocols (IACUC #702275). Once implanted with the transmitter, the fish was placed in a holding tank on the boat to recover. After the individual resumed normal behavior, it was released at the site of capture. All acoustically tagged Winter Flounder were also tagged with an external Floy tag for identification upon recapture. The reproductive condition of the tagged Winter Flounder was noted (i.e. whether it was gravid, spent or neither). Winter Flounder were categorized as gravid if the body cavity was protruding or if it was milting (Burton and Idler 1984; Elskus et al. 1994). If eggs were seen when the incision was made for the tag, the fish was considered gravid. Spent fish showed a concaved body cavity. If the body cavity was not protruding or concaved it was not considered gravid or spent.

Passive Tracking of Tagged Winter Flounder. Eleven acoustic receivers (diameter = 308 x 73 mm; VEMCO Ltd.) were mounted on concrete blocks or attached to pilings and placed throughout the inlet and creek (Figure 1). When a tagged fish swam within range of a receiver, the transmitter's ID as well as the date and time were recorded. VR2W receivers along with temperature and light loggers (Model UA-002-64, HOBO Pendant®) were used in 2015 and VR2TX transceivers were used in 2016. VR2TX transceivers record temperature, where VR2W receivers do not. Thus, water temperature was captured at three receivers in 2015 (receivers 3, 7, and 9) and at every receiver in 2016. Average, minimum, and maximum temperature was recorded every three hours at each receiver. Each receiver was placed approximately 500 m apart based on the approximate detection radius for the region and similar habitat (Divver 2012; McCauley et al. 2014). Fish that stopped being detected without going through the double gate

by the inlet, i.e. receivers 1-4 (Figure 1) were assumed to be taken by fishers or that the tag malfunctioned. Receivers 6-11 were characterized with side scan sonar as soft substrate, while receivers 1-5 were characterized by harder bottom type (Figure 1).

Two sentinel transmitters (Model V9-2L, 69 kHz, 9 x 24 mm; VEMCO Ltd.) were placed on receivers 2 and 4 (Figure 1). These tags were programmed to ping every 850 to 950 seconds for range tests between the gated receivers by the inlet. The sentinel tags were used to assess the probability that a fish would or would not be detected by the inlet gate. The daily percent coverage was calculated for receivers across from the sentinel tags: detections per day divided by 91 (the minimum amount of times the sentinel tag could be detected per day). The daily percent coverage for both receivers was then multiplied together and subtracted from 100 to determine the probability that a fish was not detected by either gate for each day.

Analysis of Telemetry Data. Receiver detections per unit effort (DPUE) were used to determine the area utilized in the creek. DPUE was calculated with the following equation:

$$DPUE = T_d / T_t$$

where T_d is the number of tags detected at a receiver, and T_t is the number of tags in the system at time t . DPUE provides an index of the abundance and habitat use of the tagged population in the system with higher values indicating areas selected by telemetered individuals. DPUE contours of the entire creek were developed in ArcMAP (ArcGIS 10.3.1). These contours represented the monthly average DPUE (tags detected/tags present per month) of each season from May 2015 to May 2017 to show the seasonal spatial behavior of telemetered Winter Flounder over two years. Daily DPUE (tags detected/tags present per day) was also calculated in the creek to achieve a finer-scale movement pattern.

165 **Migration and Residency**

166 *Migration Diversity.* Tagged Winter Flounder were categorized into two groups based on
 167 their migration patterns: (1) migrants – individuals that left the creek and did not return to the
 168 creek during the summer; and (2) residents – individuals that never left the creek or resided in
 169 the creek during the summer months (June-September). In order to test whether migratory groups
 170 consisted of different sized individuals, the mean total length at tagging of migrants that returned
 171 vs. migrants that did not return, and residents vs. migrants was evaluated with a t-test.

172 *Drivers of Migration.* To determine environmental drivers of migrant behaviors, a
 173 Generalized Linear Model (GLM) of daily counts of migrant movements (e.g., exiting or
 174 returning) in Mattituck Creek was used. Count data were fitted using a log link function, with a
 175 Poisson error distribution. Potential drivers included temperature, date, lunar cycle, photoperiod,
 176 and year. Visually inspecting the temperature values, the impact of temperature on the
 177 migrations did not appear to be linear, so a quadratic term was used for temperature in all
 178 models. All potential model configurations were given equal a priori weights; thus, the dredge
 179 function in R (R Development Core Team 2017) was used to perform automated model selection
 180 to compare all potential model combinations. Model selection was based on Akaike Information
 181 Criterion with a correction for small sample size (AICc) (Akaike 1974). Further, model
 182 evaluation was conducted using AIC weights that provide the probability of each model given
 183 the data and set of models being compared (Wagenmakers and Farrell 2004):

$$184 \quad w_i = \frac{\exp\left\{-\frac{1}{2}\Delta_i(\text{AICc})\right\}}{\sum_{k=1}^k \exp\left\{-\frac{1}{2}\Delta_k(\text{AICc})\right\}}$$

where k is the total number of models compared (R_i) and Δ_i is the difference of the AIC between all models and the optimal model (R_l). Finally, evidence ratios (ER) were provided to estimate how many times more likely R_l is compared to candidate models (R_i):

$$ER = \frac{w_{R_l}(AICc)}{w_{R_i}(AICc)}$$

The dates used for the exit migration covered the period between the first fish exiting the creek and last fish exiting the creek and the dates used for the return migration covered the period between the first fish returning to the creek and last fish returning to the creek. The dates of exiting migration were April 30, 2015 – July 2, 2016 and dates of the return migration were October 22, 2015 – December 14, 2016. All migrant fish were used in this analysis ($n=60$).

Temporal and Spatial Spawning Behavior

Spawning behavior and the approximant timing was characterized by adult telemetry, reproductive condition and back calculated spawning dates derived from YOY ageing. Potential spawning aggregation activity was defined as periods when adults congregated together for multiple days over a limited range of the creek ($DPUE > 0.6$ and > 2 days), based on telemetry observations. The value of 0.6 was used to determined periods when $\geq 60\%$ of telemetered individuals present in the system were aggregated for an extended period. Back calculated spawning data were derived from YOY otolith analysis and the relationship between age of metamorphosis and temperature (see Appendix D for details).

In the absence of direct observations of spawning, determination of spawning season can only be approached using indirect methods. More specifically, spawning date was estimated with the following steps: (1) starting with the captured YOY, otolith ageing analysis was used to estimate settlement date ($\sim$ age of metamorphosis) (Yencho et al. 2015), (2) hatching date was

then estimated utilizing the relationship of temperature and the period between hatching and metamorphosis (Laurence 1975) and (3) spawning date was estimated two weeks prior to hatching following Klein-MacPhee (2002). A visual representation of calculating the approximate spawning date is seen in Figure 2.

Environmental Data

Temperature observations were fairly uniform throughout the creek and the daily temperature was estimated as the average from all 11 receivers in 2016 (Figure 1). During December 2015-March 2016 and December 2016-March 2017, temperature was observed based on a reduced number of deployed temperature loggers to reduce the risk of equipment damage from ice. The lunar cycle was downloaded from the United States Naval Observatory website and represented the fraction of the moon's visible disk illuminated by the sun (aa.usno.navy.mil/data/docs/MoonFraction.php). Daily photoperiod was calculated as the time between sunrise and sunset in Mattituck, NY. Times for the sunrise and sunset were obtained from NOAA's Earth System Research Laboratory (<https://www.esrl.noaa.gov/gmd/grad/solcalc/sunrise.html>). All environmental data was obtained only for the dates used in the analysis.

Results

Gate Coverage. The receivers across from the sentinel tags, receivers 1 and 3, consistently detected pings from the sentinel tag (Appendix A). The sentinel tag for the first gate, i.e. receivers 1 and 2 (Figure A1a) died on October 10, 2015. The other sentinel tag for the second gate, i.e. receivers 3 and 4, remained operational (Figure A1b). The average percent coverage is 93% for the first gate and 89% for the second gate. The average probability of a fish

not being detected by either gate was 7.4% (Figure A1c). The probability of not detecting a migrating fish did not appear to be affected by tides or environmental conditions.

Receiver DPUE. All tagged Winter Flounder showed very limited movement throughout the creek, mostly residing between receivers 7-9 except in the summer months (Figure 3). The average DPUE of receivers 7-9 was 0.189-0.407 compared to the rest of the array which had DPUE values of 0.070-0.183. This area between receivers 7-9 was also where 83% of the Winter Flounder were tagged. In the summer months, the individuals that remained in the system remained mostly around receivers 1-4, i.e., closer to the inlet (Figure 3) with receiver DPUE ranging from 0.233 to 0.477.

Winter Flounder Movement Patterns. Both resident and migrant movement behavior was displayed by Winter Flounder (Figure 4A and B). Resident fish comprised 14% (n=4) of the tagged fish in 2015 and 18% (n=8) in 2016 (Table 2). Resident fish remained in the system during peak summer water temperatures that reached a maximum of 30.5°C at receiver 6 and they maintained active movement throughout the creek (Figure 4A). During the summer months, resident fish occupied the area adjacent to receivers 1-4. The rest of the year these residents were recorded near receivers 7-9 (Figure 1 and 3).

Migrant fish comprised 86% (n=24) of the tagged fish in 2015 and 82% (n=36) in 2016 (Table 2). The dates of migration for these fish ranged between April 30, 2015 and June 10, 2015 and January 5, 2016 and May 29, 2016 (Table 2). Twenty-three of the migrant fish also returned to the creek in the fall (Figure 4C). In 2015, 50% of the Winter Flounder returned to the creek as early as October 23, 2015 and as late as December 3, 2015. In 2016, 31% of the migrant Winter Flounder returned to the creek from October 25, 2016 through February 11, 2017 (Table 2). The return migration in 2016 consisted of four fish tagged in 2015 (14% of the fish tagged in 2015)

and eleven fish tagged in 2016 (25% of the fish tagged in 2016). Inspection of the data presented in Figure 5 indicated that 73% of the migrations out of Mattituck Creek were made when the water temperatures were between 7°C and 17°C, with the highest frequency around 12°C (Figure 5).

A clear optimal model for return migration was not indicated by w_i and/or ER values. The top ranked model included only date and temperature (Table 3A). GLM results indicated that temperature was not part of the optimal model for out migration (Table 3B) and included photoperiod, date, lunar cycle, and year (Table 3B). However, the second-best model contained temperature and had a similar w_i values, when compared to the other three models, indicating nearly equivalent model ranking. The first two models performed better than the remaining model configurations being 9 times more likely than other candidate models.

There was no significant difference in total length at tagging between the migrants that returned and the migrants that did not return (t-test, $\mu_r = 375.3$ and $\mu_m = 398.0$, $df = 55$, $t = 1.71$, $p = 0.09$). Resident fish were significantly smaller in total length than migrant fish (t-test, $\mu_r = 322.7$ and $\mu_m = 382.9$, $df = 16$, $t = -3.38$, $p = 0.003$). The range in total length of the resident and migrant fish are 257-431 mm and 247-473 mm, respectively.

Spawning Behavior and Timing. Monthly (Figure 3) and daily DPUE at each receiver (Figure 6A) show that there are two periods when Winter Flounder congregate between the months of October 2015 and May 2016 and then again around November 2016 through May 2017 (Figure 6A). These congregations, indicated by warm colors in Figure 6, were detected in the region near receivers 7-9 where there is soft substrate. Following the initial congregation in late October 2015, daily DPUE decreased and then increased in a longer lasting congregation during March and April 2016 (Figure 6). It is important to note that, only receivers 1-4 and 8-9

were present from December to March due to the potential loss from ice. The removal of receivers 6, 7, and 10 is evident in Figure 6A from December – March of both years as seen from the abrupt shift to dark blue (CPUE of 0) starting in December of 2015 and 2016. Receiver 9 does not start detecting fish until December 2015 despite being placed in the creek April 2015.

The approximate spawning period occurred over 5 months (Figure 6A). The first spawning event occurring on November 22, 2015 (Figure 6A), based on aggregations of adults. There appears to be a gap in spawning from December 8-22 of 2015 (Figure 6). Spawning then resumed until April 12, 2016 with peak activity February 21, 2016 and March 25, 2016 (Figure 6A). Settlement occurred over a period of three and a half months from March 19, 2016 to May 31, 2016 (Figure 6B), with peak settlement occurring April 27 and May 19 of 2016 (Figure 6B).

Discussion

Our findings highlight the behavioral complexity of Winter Flounder by documenting migration diversity, spawning behavior and year-around habitat utilization of an estuary. The majority of Winter Flounder followed the traditional view that individuals make a fall inshore spawning migration (McCracken 1963; Howe and Coates 1975; Phelan 1992). Nontraditional resident behavior was also common and occurred in both years of the study. Summer residence during temperatures reaching 30°C, considerably higher than reported optimum and lethal temperatures for the species, challenges the current understanding of the species ability to cope with seasonally warm environments.

Observed migration diversity, with migrant and resident individuals, was consistent with previous research on the South shore of Long Island (Sagarese and Frisk 2011) and historical research in the area (Olla et al. 1969). The majority of the tagged fish (83%) migrated out of the

creek in the spring while 17% of the tagged fish stayed in the creek during the summer months. Sagarese and Frisk (2011) reported a similar distribution between Winter Flounder residents and migrants in Shinnecock Bay; however, the research also reported a migratory group that moved between connected inshore bays along the south shore of Long Island. Nevertheless, residency is counter to the common view that all individuals make annual offshore migrations (Lobell 1939; Perlmutter 1947; McCracken 1963). Similar behavior was reported by DeCalles and Cadrin (2010) who observed two migratory contingents of Winter Flounder in Plymouth Bay, MA. In Plymouth Bay, one contingent spawned in estuarine waters and the other in coastal waters. Although, our data cannot speak to spawning behavior of migrants in offshore areas, we did observe 2-3 YOY cohorts in our study system suggesting the possibility of contingents spawning at different times.

The observation of resident fish in estuaries that regularly exceed reported thermal tolerances, raises questions regarding our understanding of Winter Flounder behavior and response to temperature. Previous research had reported that resident fish were able to withstand water temperatures exceeding their lethal limit (26.5–28°C) for brief periods (McCracken 1963). In Great South Bay, New York, Winter Flounder were reported to remain active up to 22°C and become inactive at 23°C (Olla et al. 1969) at which point it was suggested that they may bury as a thermal refuge. During the summer months, sediment 50-60 mm deep measured 2-3°C cooler than the water temperature (Olla et al. 1969) providing a means to escape the harsh water temperatures (Ziegler 2017). In Mattituck Creek slightly cooler temperatures towards the inlet as well as soft substrate at the back of the creek may provide an opportunity for resident fish to bury as a possible means to thermoregulate during harsh temperature conditions in the summer and winter months (Ziegler 2017).

Our finding that date, lunar cycle, photoperiod, and year cue spring out migration adds complexity to previous studies (McCracken 1963; Scarlett and Schneider 1988) that surmise temperature as the dominant factor driving migration. A common challenge with elucidating drivers of migration in a seasonal environment is separating the effects of seasonally dependent factors such as temperature with cyclic factors such as lunar cycles. Due to the small difference between the optimal and the second-best model, our results indicate that multiple factors are likely driving Winter Flounder migration back into the creek.

A combination of adult telemetry, timing of YOY settlement, and approximate spawning date estimates were used to evaluate temporal and spatial spawning patterns of the species. During the fall and winter, Winter Flounder showed preference for two locations in the creek between receivers 6 and 7 and receivers 7-9. We do not have precise data on bottom type, but from the side scan sonar, these locations appear to be almost exclusively soft substrate with patchy vegetation. Tagged individuals aggregated twice during October – December 2015 and again in late April – May 2016 in a small region of the creek suggesting spawning activity. This aggregation combined with our estimates from YOY settlement suggests Winter Flounder spawn from the end of November through April (Figure 6), a month earlier than documented by Klein-MacPhee (2002) for fish in the New England region. Winter Flounder returned to Mattituck Creek as early as October 25, 2015, but according to our spawning date analysis the first spawning date was not until November 22, 2015 (Figure 6B). This implies they are not spawning as soon as they enter the creek in agreement with Nikolsky (1963) and spawning in the system occurs over several months. Additional research on early life history survival or direct observation of spawning is needed to refine spawning dates. However, the range of spawning dates are consistent with the periods of YOY settlement that has been observed in six bays on

343 Long Island, New York, that estimated settlement dates between February and July (Frisk et al.
344 2014; Yencho et al. 2015; Gallagher et al. 2015).

345 The extended spawning period(s) is consistent with previous studies that have indicated a
346 wide range and potentially two length/age groups in YOY Winter Flounder throughout Long
347 Island (Frisk et al. 2013; Frisk et al. 2014; Yencho et al. 2015) and points towards a bet-hedging
348 life history strategy (Roff 2002). Gallagher et al. (2015) highlighted some of the trade-offs YOY
349 Winter Flounder encounter by suggesting that the optimal settlement date likely changes based
350 on temperature, food availability, and the ability to survive stressful conditions. For example,
351 settlement date of YOY Winter Flounder was negatively related to daily growth in two coastal in
352 New York during one year, but the following year settlement date was positively related to daily
353 growth in both bays (Gallagher et al. 2015). Our data indicating a prolonged spawning period,
354 along with observations reported by Gallagher et al. (2015), suggests a bet-hedging strategy
355 (Roff 2002) is used by Winter Flounder where multiple cohorts are spawned to provide a buffer
356 against environmental variability and increasing the odds that some portion of the YOY will
357 encounter favorable conditions each season.

358 As is common with field research, we were not able to address all sources of uncertainty
359 and a few caveats should be considered when interpreting findings. We were able to estimate the
360 probability of detection in our acoustic gate to be very high (>90%) and individuals were
361 consistently tracked as they moved throughout the estuary. The overall odds that an individual
362 was not detected entering and moving further (south) into the estuary were very low. It is
363 possible movements were not detected; however, they likely were few in number and would not
364 impact analyses. We were able to estimate approximant spawning time and as additional data
365 becomes available future studies may be able to quantify uncertainty in estimated spawning

366 dates. Spawning analysis would benefit from a greater understanding of the relationship between
367 temperature and the progression of early life history stages. Additionally, future studies in other
368 systems would provide insight into how our findings related to Winter Flounder stocks across the
369 species range.

370 The full migration diversity and spawning dynamics of Winter Flounder remain an
371 unresolved topic; however, as new research emerges traditional views are extended to reflect
372 greater population and behavioral diversity. Residents were significantly smaller than migrants in
373 the current study and a non-significant difference was reported by Sagarese and Frisk (2011).
374 The difference could be a phenotypic feature of a resident contingent as observed in white perch
375 (Kerr et al. 2009), or perhaps more individuals become migratory with size (Thériault and
376 Dodson 2003). Spawning appears to have occurred over a 6-month period and produced
377 differentiated age/length cohorts during settlement consistent with Yencho et al. (2015). The
378 search for generality of Winter Flounder migration behavior remains elusive; however, the
379 finding of migration diversity in three locations (DeCelles and Cadrin 2010; Sagarese and Frisk
380 2011) suggest that the phenomena may be common in the species. Current Winter Flounder
381 management does not incorporate the complexity of the species' life history and may not capture
382 the productivity of local meta-populations. Population assessments that incorporate potential
383 differential mortality and growth on respective migratory groups may improve our understanding
384 of the species population resilience and response to harvest.

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Draft

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Table 1. Summary description of Winter Flounder collected during surveys conducted in Mattituck Creek in 2015 and 2016 by month.

Year	Month	n _{total}	n _{tagged}	L _{min} (mm)	L _{max} (mm)	Male	Female	Condition	
2015	March	4	4	365	420	-	1	G-1	S-1
*	April	26	23	115	457	8	15	G-0	S-2
*	June	5	1	130	247	0	1	G-0	S-0
2016	December	5	2	118	436	0	2	G-2	S-0
*	January	18	12	124	473	4	14	G-12	S-0
*	February	20	20	257	465	10	10	G-9	S-4
*	March	11	10	251	432	5	6	G-5	S-2
Total		89	72			27	49	29	9

n_{total}=total number of Winter Flounder caught; n_{tagged}=number of Winter Flounder tagged (fish needed to be a minimum of 240 mm to be tagged); L_{min}= minimum length; L_{max}=maximum length; Condition=condition of the fish when caught (G gravid, S=spent).

Note: Sex was determined for tagged adults based on the smoothness of the ventral surface. Sex determination was not conducted prior to March 2015. Fish condition was only noted for tagged individual that appeared visibly gravid (G) or spent (S). Only individuals with noted condition are included.

Table 2. Summary of adult Winter Flounder movements in Mattituck creek in 2015 and 2016.

Year	Migrated out	Dates of migration	Survived and returned	Dates of return	Residents
2015	86% n=24	April 30, 2015 – June 10, 2015	50% n=12	October 23, 2015 – December 3, 2015	14% n=4
2016	82% n=36	January 5, 2016 – May 29, 2016	31% n=11	October 25, 2016 – February 11, 2017	18% n=8
Average	83%		38%		17%

Note: The statistics for each year are based on the number of Winter Flounder that were tagged in that year only. The survived and returned percentages are of the fish that migrated out of the creek. The statistics for the total are based on the 72 tagged individuals over the two years of this study.

534 Table 3. Top 5 GLM results for factors driving **(A)** Winter Flounder migrations into the creek
 535 and **(B)** Winter Flounder migrations out of the creek. The first models are the optimal models.

A. Movement into the Creek						
Model	df	LL	AICc	w _i	ER	
D-T	3.0	-119.1	244.2	0.36	1.0	
D-P-T	4.0	-118.4	244.8	0.27	1.3	
D-P-Y	4.0	-119.0	246.1	0.14	2.6	
D-L-P	4.0	-119.1	246.1	0.14	2.6	
D-L-P-T	5.0	-118.8	246.8	0.10	3.7	
B. Movement out of the Creek						
D-L-P-Y	5.0	-230.3	470.6	0.59	1.0	
D-L-P-Y-T	6.0	-230.0	472.0	0.29	2.0	
D-L-P	4.0	-233.5	475.0	0.07	9.0	
D-L-P-T	5.0	-233.3	476.7	0.03	21.1	
D-P-Y	4.0	-234.5	477.1	0.02	25.8	

536 D=date; L=lunar cycle; P=photoperiod; Y=year; T=temperature; df=degrees of freedom; LL=log
 537 likelihood; AICc=Akaike information criterion corrected for small sample size; w_i=Akaike
 538 weights; ER=evidence ratios.

Figure 1. Map of the study area, Mattituck Creek, Long Island, New York. Red dots identify submerged acoustic receiver locations. The numbers by the red dots represent the receiver number. Areas indicated by S followed by a number represent the ten different strata of equal area.

545

546 Figure 2. Estimation of spawning date flowchart. The captured YOY Winter Flounder were aged
 547 using their otoliths to estimate their settlement dates. After, temperature information from
 548 Laurence (1975) was used to estimate the hatching date. An additional 14 days were then
 549 subtracted from the hatching date to determine the approximate spawning date.

Figure 3. Seasonal average DPUE (tags detected/tags present per month) in the creek over spring, summer, fall and winter of 2015 and 2016. Warmer colors represent high DPUE values, cooler colors represent low DPUE values. Seasons correspond to May, July, November, and March, respectively.

Figure 4. Movement patterns of (A) an individual resident, (B) an individual migrant, and (C) an individual migrant that returned. Each black dot represents a detection in the array.

Figure 5. Migration of fish (primary y-axis) relative to date (x-axis) and average water temperature (secondary y-axis), indicated by the red line, in Mattituck Creek. The dashed red line is the thermal threshold for Winter Flounder based on studies done by McCracken (1963). The blue boxes highlight the times when the majority of the fish made their migration out of the creek.

567

568 Figure 6. (A) A heat map illustrating the DPUE of adult tagged Winter Flounder. Warm colors

569 indicate high DPUE values and cool colors indicate low DPUE values. (B) Estimated spawning

570 dates of adult Winter Flounder. (C) Estimated settlement dates of the YOY Winter Flounder.

1 **Appendix A**

5 Figure A1. Sentinel tag coverage of the gated receivers by the inlet. Sentinel tags were attached
6 to receivers 2 and 4, across from receivers 1 and 3 respectively (**a** and **b**). Probability of a fish
7 not being detected by either gate per day (**c**).

- 8 **Note:** As of October 10, 2015, only one sentinel tag was operational. Probabilities in (c) were
9 only during the period when both sentinel tags were operational.

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Appendix B

YOY Abundance, Age and Settlement Date. In the summer of 2016, 92 YOY Winter Flounder were caught in Mattituck Creek in 71 tows. The total length of the YOY Winter Flounder ranged from 24 to 102 mm in 2016. Of the 92 YOY caught, 51 of them were used for otolith analysis. YOY were present throughout the creek except near the inlet (Figure 1: S1 and S2). The largest proportion of YOY (34.8%) were caught in strata 7, near receiver 8 (Figure 1).

The total lengths of the aged YOY individuals caught in 2016 ranged from 24 to 97 mm (average = 48.4, median = 41.5), with age at settlement ranging from 25 to 113 days (average = 65, median = 60). A linear regression showed that length was positively related to age at settlement ($y = 0.99x + 16.64$, $r^2 = 0.8144$, $n = 52$, $t = 14.81$, $p\text{-value} = <0.0001$).

20 **Appendix C**

21 *Otolith Ageing:* Sagittal otoliths were used to determine the age of YOY Winter
22 Flounder. The left sagittal otoliths from YOY Winter Flounder were extracted and cleaned under
23 a dissection microscope and allowed to dry on a microscope slide. Left otoliths were used for
24 growth and ageing purposes because they were shown to be a more reliable estimator of prior
25 somatic growth rates than the right sagittal otolith (Sogard 1991). Once dry, the otoliths were
26 glued to the slide with Crystalbon 509 adhesive. Otoliths were polished whole in the sagittal plan
27 using 30- μ m and 3- μ m lapping paper (3M). Polishing was done until the increments between the
28 secondary growth center and the edge of the otolith, which represent the post-metamorphic age
29 of the individual, were in focus. Photographs were taken on a Nikon DX1200C digital camera
30 attached to a Nikon eclipse 80i compound microscope. Due to the shape of the otoliths, pictures
31 were taken at multiple points during the polishing process. This was to account for the possibility
32 of over-polishing one area in the process of getting another area in focus. The daily increments
33 were counted from the edge of the otolith to approximately 10 increments away from the
34 formation of the secondary growth center as done in Gallagher et al. (2015). Otoliths from YOY
35 Winter Flounder from June and July 2016 were counted three times, selecting the average of the
36 three readings, to determine the age at settlement. Once the age was determined from the otolith
37 readings, that number was subtracted from the date of capture to establish the settlement date.

38 **Appendix D**

39 *Spawning Date*. The YOY otoliths were chosen for ageing based on the following
40 criteria: (1) for each week sampled, fish were aged from all length classes present to represent
41 the entire range of observed lengths and (2) an otolith was not processed if the image was not
42 legible.

43 The length of time between hatching and metamorphosis was calculated for individuals
44 using the average daily water temperature observed in Mattituck creek 60 days prior to
45 settlement and the Laurence (1975) experimental results relating temperature and time to
46 metamorphosis. Sixty days was used since this is the average age at metamorphosis from
47 hatching to settlement as seen in Chambers and Leggett (1987). Specifically, a power function (
48 $M = 346.94T^{-0.931}$) fit to experimental results for 2, 5, and 8°C (Laurence 1975) was utilized to
49 predict the length of time to metamorphosis (M) in relation to temperature (T). The power
50 function was used to fill in missing values in the relationship and was not analyzed statistically.

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