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Estimating the abundance and egg production of spawning winter flounder (*Pseudopleuronectes americanus*) in the Niantic River, CT for use in the assessment of impact at Millstone Nuclear Power Station

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Abstract

The winter flounder is a coastal flatfish with spawning populations associated with specific estuaries or coastal areas. Because of its stock structure, this species is susceptible to localized impacts, including power plant entrainment of larvae. Winter flounder rank second in fish larvae entrained at the Millstone Nuclear Power Station (MNPS), located on Long Island Sound in Waterford, CT, USA. Because of its importance to the state's fisheries, the population spawning in the nearby Niantic River was selected for impact assessment studies in the early 1970s. Northeast Utilities has consistently monitored annual abundance of adult spawners, characterizing relative abundance by trawl catch-per-unit-effort (CPUE) and absolute abundance using mark and recapture data with the Jolly model for demographically open populations. Trends in these two independent but highly correlated indices provide short-term assessments of winter flounder abundance. Abundance of winter flounder peaked in the early 1980s, but as fishing mortality increased to high levels in the late 1980s, their numbers declined thereafter and presently are very low. Information on sex ratio, length-frequency distribution, and spawning condition allow for calculation of annual egg production using a length-fecundity relationship. This forms the basis for estimating production loss due to larval entrainment, which is used as input to a long-term assessment model of power plant impact, discussed in an accompanying paper (Lorda et al., 2000: Lorda, E., Danila, D.J., Miller, J.D., 2000. Application of a population dynamics model to the probabilistic assessment of CWIS effects of Millstone Nuclear Power Station (Waterford, CT) on a nearby winter flounder spawning stock. Environmental Science & Policy 3, S471–S481). © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Winter flounder; Mark and recapture; Population study; Stock assessment; Power plant impacts

1. Introduction

The winter flounder (*Pseudopleuronectes americanus*) has been the subject of environmental impact studies by Northeast Utilities Service Company (NUSCO) at the Millstone Nuclear Power Station (MNPS) since 1973. MNPS is situated on Millstone Point, about 8 km west-southwest of New London on the Connecticut shore of Long Island Sound (LIS) (Fig. 1). The MNPS complex consists of three operating nuclear power units: Unit 1, a 660-MWe boiling water reactor, which began commercial operation in November 1970; Unit 2 is an 870-MWe pressurized water reactor (PWR) with commercial operation beginning in December 1975; and Unit 3 (1150-MWe PWR), which commenced commercial operation in April 1986. Unit 1 ceased operation in November 1995, and in July 1998, Northeast Utilities announced its retirement. All three units were designed to use once-through condenser cooling, with rated circulating water flows of 26.5, 34.6, and 56.6 m^3 s^{-1} for Units 1–3, respectively. The amount of cooling-water used has varied throughout

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the life of the station, depending upon plant operation. More detailed descriptions of the station, its surrounding environment, and the environmental monitoring studies being performed to fulfill regulatory requirements are found in annual ecological monitoring reports (NUSCO (Northeast Utilities Service Company), 1998).

The winter flounder is an important sport and commercial fish in Connecticut (Smith et al., 1989) and is a dominant member of the local demersal fish community. This species occurs from Labrador to Georgia, but is most numerous in the central part of its range (Scott and Scott, 1988), which includes LIS. Its seasonal movements and reproductive activities are well-documented (Klein-MacPhee, 1978). Most adult fish enter inshore waters in late autumn and early winter and spawn in upper portions of natal estuaries during late winter and early spring at temperatures between 1 and 10°C (peaking at 2–5°C) and salinities of 10–35‰ (Bigelow and Schroeder, 1953; Pearcy, 1978). Near MNPS, most males mature at age 2 and females at ages 3–5; the average fecundity of females is about 561,000 eggs (NUSCO, 1987). Greatest viable hatch occurs at 3°C and decreases with increasing temperature (Rogers, 1976). The demersal adhesive eggs hatch in about 15 days, and larval development takes about 2 months with both processes being temperature-dependent. Small larvae are planktonic and although many remain near the estuarine spawning grounds, others are carried into coastal waters by tidal currents (Smith et al., 1975; NUSCO, 1989; Crawford, 1990). Some displaced larvae have been found to return to the estuary on subsequent incoming tides, but many are swept away into coastal waters, where their probability of survival is questionable. Larger and older larvae, which are more developed, maintain some control over their spatial position by vertical movements and may spend considerable time on or near the bottom. Following metamorphosis, winter flounder become demersal and most move into shallow inshore waters. Some adults remain in estuaries following spawning, while others disperse offshore as their preferred temperature range is 12–15°C (McCracken, 1963).

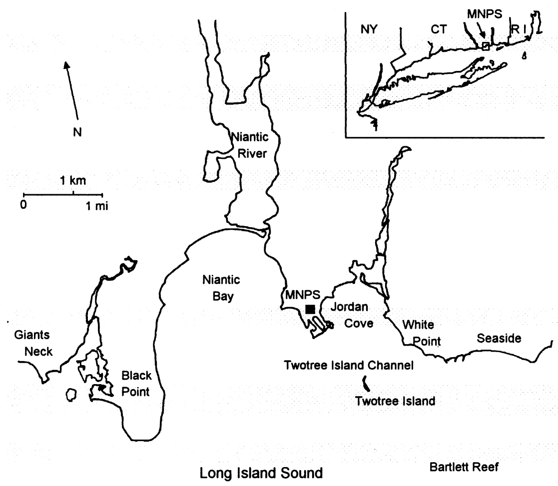

Fig. 1. Location of Millstone Nuclear Power Station (MNPS), Waterford, CT.

MNPS operation can result in the impingement of juvenile and adult winter flounder on the intake traveling screens and the entrainment of larvae through the cooling-water intake system (CWIS), which has been previously described (Jacobson et al., 1998). The impact of impingement at MNPS was addressed by the installation and operation of fish return sluiceways. However, unlike many marine fishes having widespread distribution of their populations and great abundance, mortality of entrained winter flounder larvae potentially has greater significance as larvae are products of local spawning from relatively geographically isolated populations associated with specific estuaries or coastal areas (Lobell, 1939; Perlmutter, 1947; Saila, 1961). The population of winter flounder which spawns in the nearby Niantic River has been studied in detail to assess the long-term effect of larval entrainment through the MNPS CWIS.

The Niantic River is a small (320 ha) coastal embayment in southeastern Connecticut, with a maximum length of about 5.25 km and maximum width of about 1.2 km (Fig. 1). River is perhaps a misnomer as this lagoon-type estuary receives limited freshwater input, mostly from two small streams that enter its northern reaches. Except during large precipitation events, salinities in most of the river tend to be similar to those of LIS and usually range from the mid-20s to 30‰. The river is well flushed with tidal exchange approximately 50% of low tide water volume. More of the water from the southern portion is exchanged with LIS than from the northwestern arm (Kollmeyer, 1972). Water temperatures in the river tend to be cooler in winter and warmer in summer than LIS. Monthly mean temperatures recorded in LIS at MNPS during the past 23 years ranged from a low of 0.36°C in February 1997 to a high of 21.24°C in August 1985. The mouth of the river is about 1.8 km from the MNPS intakes and during three-unit operation about 20% of the river discharge volume passes through the plant CWIS (Dimou and Adams, 1989).

Presently, a combination of various field sampling programs and analytical methods are used to assess impact to the Niantic River winter flounder spawning stock. A computer population simulation model, the NUSCO stochastic population dynamics model (SPDM), is used to examine long-term population effects of MNPS operation (Lorda et al., 2000). The annual adult population study described below provides information on the current abundance of this spawning unit. Abundance estimates are used with other life history data to determine annual egg production, initializing calculations of larval production loss that are necessary as key inputs to the SPDM.

2. Materials and methods

Studies of adult winter flounder during the spawning season in the Niantic River using a survey design similar to the present one were initiated in 1976 and have remained essentially unchanged since 1983. An annual survey usually begins between mid-February and mid-March, after most ice cover disappears from the river, and continues into April. Sampling ceases when the proportion of reproductively active females of ≥26 cm in total length (TL) decreases to less than 10% of all similarly-sized females for 2 consecutive weeks in the sampling, an indication that most spawning is completed. For each survey, the Niantic River was divided into a number of sampling areas, referred to as stations (Fig. 2). Winter flounder were collected on at least 2 days of each week using a 9.1-m otter trawl with a 6.4-mm bar mesh codend liner. Fish caught in each tow were held in water-filled containers aboard the survey vessel before processing. Since 1983, each fish 20 cm or larger was measured to the nearest mm (TL), and its gender and reproductive condition ascertained. Before 1983, not all fish were measured, but were grouped by length and gender; at minimum, all winter flounder examined were classified as smaller or larger than 15 cm. Gender and reproductive condition of larger winter flounder was determined by either observing eggs or milt, or noting the presence (males) or absence (females) of ctenii by palpating the left-side caudal peduncle scales (Smigielski, 1975). Before release, uninjured fish larger than 15 cm (1977–1982) or 20 cm (1983 and after) were marked at a specific body location with a number or letter made by a brass brand cooled in liquid nitrogen. Marks and brand location were varied in such a manner that the year of marking would be apparent in future collections.

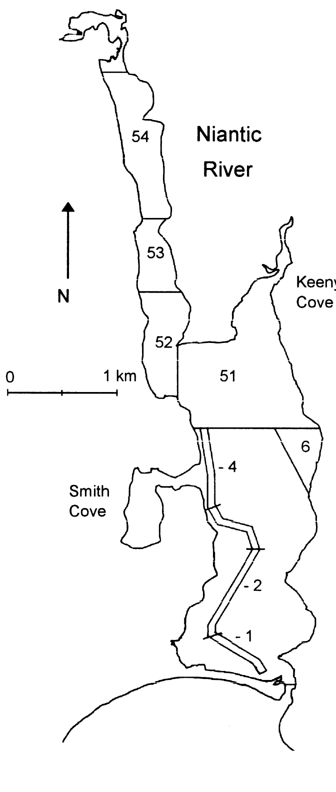

Fig. 2. Location of stations sampled in the Niantic River during adult winter flounder spawning surveys.

Annual relative abundance is measured by trawl catch-per-unit-effort (CPUE). Components of standardization for CPUE calculations included tow distance, time duration, and weekly effort. Length of tows is measured, and tow distance was fixed at all stations (with some exceptions) at 0.55 km in 1983 because this was expected to reduce variability in CPUE. Previously, tows of variable length had been taken at all stations, and catch was standardized by time of tow. Shorter tows were occasionally made to avoid overloading the trawl with macroalgae and detritus. Duration of tows varied and was usually greater in the lower river than in the upper river because of differences in tidal currents and amounts of extraneous material collected in the trawl, even though distance was similar. To reduce error in calculating CPUE, data from either exceptionally long or abbreviated tows made prior to 1983 were excluded from the analyses. Because of the lack of a standardized tow distance prior to 1983, catches of winter flounder larger than 15 cm were standardized by time to either 15-min tows at stations 1 and 2 or 12-min tows at all other stations. The minimum fish length of 15 cm used for CPUE calculation was smaller than the 20 cm used for mark and recapture estimates described below because of data limitations from the 1977 to 1982 surveys. Finally, for purposes of calculating CPUE, effort was standardized within each year by replicating as necessary the median CPUE value for a given week such that the number of tows used in the calculation was the same for every week sampled.

A second relative index of abundance was based on the size distribution of female fish from adult spawning survey catches standardized by variable weekly and yearly effort (i.e., number of tows). Catches were adjusted by sampling effort to insure that each size group of fish was given equal weight within each week of work, among weeks in each survey year, and to adjust for varying effort among years (NUSCO, 1989).

To avoid confusion with the CPUE index, this adjusted catch index is referred to herein as 'annual standardized catch'. The annual standardized catch of females initiated the calculation of annual egg production estimates.

Absolute abundance estimates (N) of the winter flounder spawning stock in the Niantic River were obtained using mark-and-recapture methodology and the Jolly stochastic model (Jolly, 1965). This model is among the most appropriate ones for demographically open populations as long as basic assumptions are approximately met (Cormack, 1968; Southwood, 1978; Begon, 1979; Pollock et al., 1990). Estimates of N for winter flounder larger than 20 cm were calculated by pooling together all fish marked and released during each annual survey and by observing the recaptures

Table 1
Annual 9.1-m otter trawl adjusted Δ-mean CPUE of winter flounder larger than 15 cm taken throughout the Niantic River during the 1976–1998 adult population abundance surveys

Survey year	Dates sampled	Tows acceptable for CPUE[a]	Adjusted number of tows used[a]	Non-zero observations	Δ-mean CPUE estimate	Standard error	95% confidence interval for Δ-mean CPUE
1976	1 March–13 April	169	224	222	48.4	2.9	42.7–54.1
1977	7 March–12 April	223	264	261	27.5	1.7	24.3–30.8
1978	6 March–25 April	150	174	174	31.2	2.3	26.6–35.7
1979	12 March–17 April	127	140	140	41.0	4.0	33.0–48.9
1980	17 March–15 April	117	150	149	41.5	2.9	35.9–47.1
1981	2 March–14 April	181	232	232	50.8	2.5	45.9–55.7
1982	22 February–6 April	118	149	149	47.8	3.5	41.0–54.6
1983	21 February–6 April	232	238	237	31.3	1.3	28.8–33.9
1984	14 February–4 April	246	287	286	18.4	0.7	17.1–19.7
1985	27 February–10 April	268	280	277	17.1	0.7	15.7–18.5
1986	24 February–8 April	313	343	341	12.2	0.5	11.2–13.3
1987	9 March–9 April	234	270	267	16.9	0.9	15.2–18.6
1988	1 March–5 April	292	312	310	17.9	0.7	16.5–19.3
1989	21 February–5 April	272	306	302	13.9	0.7	12.6–15.1
1990	20 February–4 April	307	343	342	11.2	0.5	10.3–12.2
1991	13 February–20 March	301	330	324	16.7	0.9	14.9–18.5
1992	18 February–31 March	380	406	395	7.7	0.3	7.0–8.3
1993	16 February–7 April	288	392	344	3.4	0.2	3.0–3.7
1994	22 March–13 April	185	212	201	6.4	0.5	5.5–7.3
1995	28 February–6 April	320	342	283	2.6	0.1	2.4–2.9
1996	27 February–3 April	310	342	242	1.6	0.1	1.4–1.8
1997	18 February–25 March	302	348	288	2.4	0.1	2.2–2.6
1998	9 February–1 April	363	385	306	2.1	0.1	1.9–2.3

[a] Effort equalized among weeks. During several years, weeks having very low effort were not used to compute CPUE.

made in subsequent years. Absolute abundance could not be determined prior to 1984 because of uncertainty in data records and ambiguity caused by brands used during the early surveys. N was estimated using the computer program 'JOLLY' (Pollock et al., 1990).

The proportion of mature female winter flounder in each 0.5-cm length increment beginning at 20 cm was estimated from qualitative observations of reproductive condition (percent maturity by 0.5-mm size-classes) made from 1981 to the present. Pooled estimates were adjusted to give continuously increasing fractions of mature fish through 34 cm; all females this length or larger were considered to be mature. The fecundity (annual egg production per female) was estimated for each 0.5-cm size-class by using the following relationship determined for Niantic River winter flounder (NUSCO, 1987):

$$\text{fecundity} = 0.0824 \cdot (\text{length in cm})^{4.506} \qquad (1)$$

The above relationship was used with the annual standardized catch of mature females and their length composition to calculate total egg production. Annual mean fecundity was determined by dividing the sum of all individual egg production estimates by the standardized catch of females spawning each year. Absolute estimates of spawning females and corresponding annual egg production estimates for 1977–1998 were determined by assuming that the relative values represented 4% of the absolute values (see Section 3.2 for how this fraction was determined).

3. Results and discussion

3.1. Relative annual abundance

Survey start and completion dates varied annually and depended upon ice cover in the river and spawning (Table 1). The number of weeks sampled ranged from 4 in 1994, a year during which very heavy ice cover forced the latest start of the sampling in 23 years, to 8 weeks sampled in several years, either because of extended spawning occurring during a cold winter (e.g., 1978) or from early starts (1984, 1993). Because a majority of the females was spent at the beginning of most surveys, considerable spawning apparently occurs in early winter. Exceptions have included extremely cold years (1977, 1978, and 1996), when many gravid females were found, even after relatively late starting dates because of heavy ice cover. In contrast, during warmer years (1989, 1992, and 1997), a greater proportion of observed females was spent, even when sampling commenced earlier. In all years, most spawning was completed by late March or early April. When abundant, winter flounder were present throughout the river, but more recently, most adult spawners were found concentrated in relatively small areas, including the northwestern river arm (stations 52–54), particularly at station 54. Few fish were collected at stations 1, 2, and within most of station 51 (Fig. 2). The eastern shoreline of the river within stations 6 and 51 was an area in which ripe males were more abundant than females, indicating a likely spawning location or staging area.

Relative annual abundance of spawning winter flounder in the Niantic River is characterized by a Δ-mean CPUE. Prior to 1993, 97–100% of the tows taken each year had at least one winter flounder, but this fraction varied between 68 and 94% since then. A Δ-mean is considered to be the best estimator of the mean for abundance data approximating a lognormal distribution and containing numerous zero catches (Pennington, 1983, 1986). Annual sample size varied according to total effort, ranging from 117 tows in 1980 to 363 in 1998; more tows have been made in recent years because fewer winter flounder and less detritus allowed for greater daily effort (Table 1). Similarly, the adjusted number of tows used in the calculation of CPUE varied, not only by the number of tows that were taken, but how the effort was distributed among weeks; annual totals ranged between 140 (1979) and 406 (1992). The Δ-mean CPUE of winter flounder larger than 15 cm peaked at 50.8 in 1981 and 47.8 in 1982 as fish from the extremely large year-classes of 1977 and 1978 that were observed as juveniles in various sampling programs eventually recruited into the adult spawning population (Table 1; Fig. 3). CPUE indices declined to about a third of those levels during the remainder of the 1980s. Further large decreases in abundance occurred in the early 1990s and, again, in more recent years, reflecting current extremely low adult stock sizes that have resulted primarily from high rates of fishing (NEFSC (Northwest Fisheries Science Center), 1998). CPUE during 1995–1998 ranged between 1.6 and 2.6, which equates to about 5% or less of peak abundance.

3.2. Absolute abundance estimates

The number of winter flounder ≥20 cm captured, freeze-branded, and released back into the Niantic River varied among years (Table 2). Numbers marked were highest in the early 1980s, but declined greatly since 1994 because of low spawner abundance. Recaptured winter flounder were at large for as long as 8 years. Beginning in 1994, the number of recaptures decreased substantially. Not including 1984 or 1985 (the first 2 years of the series), fish recaptured that were marked during the preceding year accounted for about one-half to two-thirds of all recaptures, except for 1994 (36%) and 1997 (33%). For both of the latter

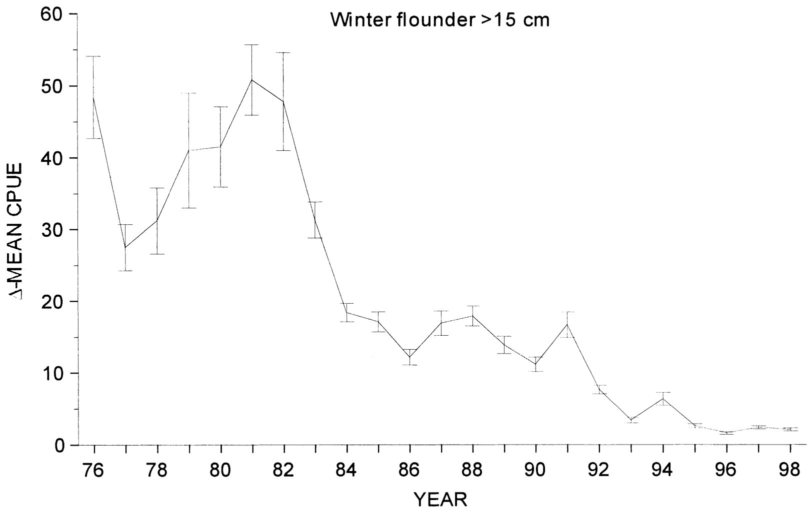

Fig. 3. Annual Δ-mean CPUE and 95% confidence interval of Niantic River winter flounder larger than 15 cm taken in adult spawning surveys from 1976 to 1998.

years, relatively small numbers of fish were marked during the preceding year in comparison to earlier years. Absolute abundance estimates of winter flounder varied between 6800 and 66,700 fish (Fig. 4). A pattern similar to that for CPUE was observed, with particularly low (< 10,000 fish) annual abundance estimates for recent years, in contrast to estimates of more than 50,000 fish for the mid-1980s. Population estimates for the most recent years, however, are subject to change as additional recaptures are made during subsequent surveys. For example, with an additional year of recapture data, an initial estimate of nearly 7200 fish made for the spawning stock in 1996 increased to about 9300 fish the following year.

Several assumptions for capture–recapture population models should be met for reliability of parameter estimates (Arnason and Mills, 1981; Pollock et al., 1990). Geographical closure was readily met for this population as all spawning fish were believed to be confined to the well-bounded Niantic River, based on concurrent sampling in Niantic Bay and other areas of LIS. Marked and unmarked fish must be equally catchable. A freeze brand is unlike a physical tag, such as a Petersen disc, which could differentially catch on trawl netting. We do not believe that the brand affected behavior, particularly since recaptures take place 1 year or more after marking (within season recaptures are ignored).

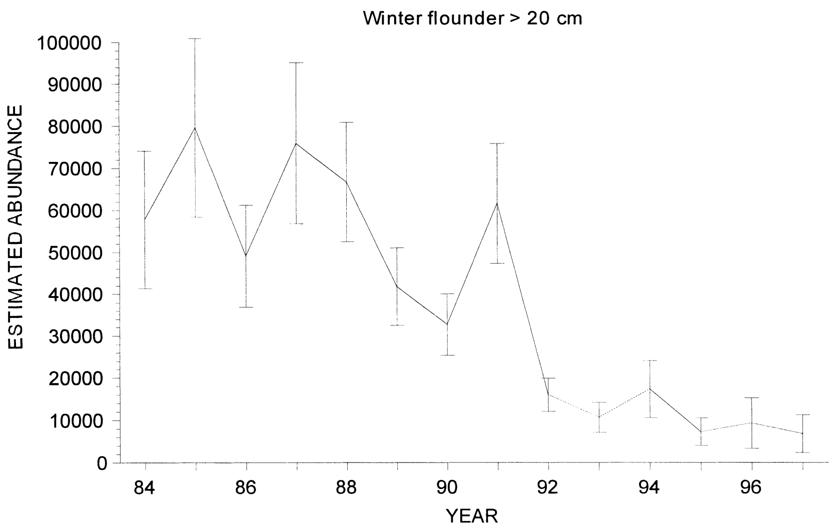

Fig. 4. Estimated annual absolute abundance and 95% confidence interval of Niantic River winter flounder larger than 20 cm taken in adult spawning surveys from 1984 to 1997.

Table 2
Mark and recapture data from 1983 to 1998 used to estimate abundance of winter flounder larger than 20 cm in the Niantic River during the spawning season

Survey year	Number observed	Number not previously marked	Number marked and released	Number recaptured
1983	5615	5615	5615	0
1984	4103	3973	4083	130
1985	3491	3350	3407	141
1986	3031	2887	3010	144
1987	2578	2463	2573	115
1988	4333	4106	4309	227
1989	2821	2589	2752	232
1990	2297	2135	2275	162
1991	4333	4067	4324	266
1992	2346	2119	2336	227
1993	984	830	972	154
1994	1035	959	1033	76
1995	682	601	681	81
1996	379	341	376	38
1997	642	603	642	39
1998	676	637	671	39

Number of fish marked in a given year that were recaptured during subsequent annual surveys

Survey year	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
1984	130														
1985	47	94													
1986	23	45	76												
1987	2	13	27	73											
1988	7	22	31	63	104										
1989	2	11	9	33	32	145									
1990	1	7	4	15	14	38	83								
1991	1	5	4	12	27	33	54	130							
1992	0	0	1	2	3	21	20	53	127						
1993	0	0	0	1	0	4	4	15	21	109					
1994	0	0	0	1	0	0	4	5	14	25	27				
1995	0	0	0	0	0	1	1	2	8	8	18	43			
1996	0	0	0	0	0	0	0	2	2	5	5	4	20		
1997	0	0	0	0	0	0	0	2	1	6	3	5	9	13	
1998	0	0	0	0	0	0	0	0	0	1	2	4	6	2	24

Marked and unmarked fish should have equal probability of survival and branded Niantic River winter flounder were held in the laboratory to confirm this. Finally, there should be no loss of marks. In our opinion, this is the most difficult of the assumptions to meet for this particular study and is likely violated to some degree. Freeze brands can fade or become obscure, may be noticed but have become too difficult to read, or may be overlooked by workers. Loss of information because brands were missed or due to mortality of fish handled also requires increased sampling efforts. However, simulation studies performed by Arnason and Mills (1981) showed that estimates of N are not overly biased by tag loss, although there is a loss in precision. Under certain conditions, other sampling errors, model assumptions, and biases inherent in the Jolly model can also affect parameter estimates from the Jolly model (NUSCO, 1989; Pollock et al., 1990).

Although the Jolly abundance estimates are subject to error, annual estimates of Δ-mean CPUE and absolute abundance were significantly correlated (Spearman's rank-order correlation coefficient $r = 0.9519$; $p = 0.0001$). Thus, based on a Δ-mean CPUE of 2.1 for 1998, absolute abundance of winter flounder was likely less than 10,000 fish for that year, even though a mark and recapture estimate is not yet available. By extrapolation, abundance in 1981 (prior to absolute abundance estimation for the Niantic River spawning stock because of differing methodology) may have exceeded 150 to 200 thousand adult winter flounder.

Since a reasonable correspondence exists between median trawl CPUE and Jolly abundance estimates, the annual standardized catches of all fish larger than 20 cm for 1984–1997 were compared to total abundance estimates from the Jolly model to determine a scaling factor. Relative numbers of females and eggs produced each year, as determined from the standardized catches, were conservatively assumed to represent about 4% (geometric mean value) of the absolute values, with annual values ranging between 2.8 and 6.2%. Thus, a multiplier of 25 was used to scale the relative abundance standardized catch estimates of spawning females to absolute numbers that are given below. In using this scaling factor it was assumed that ratios of annual standardized catch to absolute abundance during 1977–1983 would have been similar to those of later years had estimates of absolute abundance been available for the earlier period. This methodology was necessary to generate egg production estimates because mark and recapture data amenable for the Jolly model were not available for years prior to 1983. Further, even though in subsequent years mark and recapture data were on hand and could have been partitioned by gender, this effectively halved the amount of data used with the model and resulted in imprecise and likely inaccurate estimates for both males and females.

3.3. Spawning stock size and egg production

The size of the Niantic River winter flounder female spawning stock is used in various assessments of MNPS impact. The annual standardized catch of female spawners (an index of spawning stock size) and the production of eggs were determined from available data on sex ratios, sexual maturity, fish length-frequencies, and the length–fecundity relationship. Except for 1986 and 1987, annual sex ratios of winter flounder larger than 20 cm were in favor of females. The long-term average was 1.48 females for each male over the 22-year time-series (range of 0.78–2.70). In general, sex ratios with females predominating have increased ($\geq$1.70) in recent years as overall winter flounder abundance decreased. Mature winter flounder females are larger than males, and greater exploitation of females by the fisheries might have been expected, which should have disproportionately decreased their numbers. However, this was contrary to the findings and may have resulted from susceptibilities that differed by gender for fishing (e.g., availability), natural mortality (e.g., predation, disease), and availability to our research trawl sampling during the winter flounder survey (e.g., spawning males remaining in shallow areas not sampled). Sex ratios of 1.50–2.33 in favor of females were found in other winter flounder populations of southern New England (Saila, 1962a,b; Howe and Coates, 1975; Witherell and Burnett, 1993). Proportionately more older females and skewed sex ratios may also result from, in part, greater senescent mortality that has been observed for males (Burton and Idler, 1984).

About half of the Niantic River females larger than 26 cm are mature. This length is comparable to L_{50} estimates of size-at-maturity of 25.8 cm reported for LIS (Johnson et al., 1998) and 28.3 and 27.6 cm for Massachusetts waters (O'Brien et al., 1993; Witherell and Burnett, 1993). With only a fraction of Niantic River female winter flounder between 20 and 30 cm mature, most spawners were larger than 31 cm (mostly $\geq$age-4^{+}). The largest female winter flounder collected to date in the river was 50.8 cm. Although not numerically abundant, larger and older fish now comprise a relatively larger proportion of female winter flounder in the Niantic River than in past years. During each year, the proportion of mature females by length was used with annual standardized catch indices to obtain the abundance of female spawners. Estimates of female stock size ranged from a maximum of 68,210 fish in 1982 to a minimum of 2349 in 1996 (Table 3). Mature females generally comprised about one-third to one-half of each annual total estimate. Highest percentages were found in recent years, including 1995 (62%) and 1997 (59%), a result of highly skewed sex ratios and proportionately larger fish found during these years.

Annual total egg production estimates ranged from about two and 39.5×10^9 eggs (Table 3). Differences in percent maturity due to changes in length-frequency distributions somewhat affected mean fecundity, which was low during the late 1970s when smaller fish were more abundant, but increased during recent years because of increasing proportions of older and larger fish. Total egg production was greatest from 1981 to 1983 because of peak population abundance and moderate mean fecundity estimates. Egg production was also relatively high in 1988, 1989, and 1991, as proportionally older and larger females dominated moderately-sized reproductive stocks. Total fecundity decreased to relatively low values in recent years because of very low winter flounder abundance. Although some density-dependent regulatory mechanisms have been proposed for adult flatfishes, size-specific fecundity appears to be stable over a wide range of abundances (Rijnsdorp, 1994). Thus, no annual adjustments were considered for the Niantic River winter flounder length–fecundity relationship. The yearly egg production estimates formed the basis for estimating production loss due to larval entrainment at MNPS and were inputs to the SPDM, a long-term assessment model of plant impact (Lorda et al.,

Table 3
Annual standardized catch of female winter flounder spawners calculated total female stock size and total egg production estimates in the Niantic River from 1977 to 1998

Survey year	Annual standardized catch of spawning females[a]	% mature females[b]	Average fecundity[c]	Total female spawner stock size[d]	Total egg production ($\times 10^9$)[d]
1977	1146	36	447,379	28,638	12.812
1978	1753	51	502,326	43,819	22.011
1979	1292	38	468,032	32,306	15.120
1980	1089	34	460,732	27,229	12.545
1981	2586	44	516,603	64,660	33.404
1982	2728	49	578,472	68,210	39.458
1983	1820	46	577,304	45,493	26.263
1984	878	40	576,623	21,947	12.655
1985	906	43	606,510	22,660	13.743
1986	644	42	666,314	16,112	10.736
1987	831	39	623,185	20,774	12.946
1988	1248	53	677,475	31,196	21.134
1989	949	52	727,863	23,723	17.267
1990	533	41	629,768	13,322	8.390
1991	1025	47	601,260	25,632	15.412
1992	516	52	732,365	12,905	9.452
1993	264	54	816,831	6593	5.385
1994	487	55	649,678	12,177	7.911
1995	204	62	767,763	5097	3.913
1996	94	52	844,911	2349	1.984
1997	176	59	785,510	4405	3.460
1998	126	54	746,754	3141	2.346

[a] Based on proportion of the annual standardized catches that were mature females.
[b] As a proportion of all winter flounder 20 cm or larger.
[c] Total egg production divided by the number of spawning females.
[d] Calculated on the assumption that relative standardized catches were approximately 4% of absolute values.

2000). Despite low abundance of spawners at the present time, adult winter flounder remain capable of producing large numbers of larvae, with relative larval densities as great in recent years as they were when adult spawners were considerably more abundant (NUSCO, 1998). High larval abundance, under appropriate conditions, can further result in a relatively strong year-class of demersal age-0 juveniles, although this life stage also is subject to considerable annual variation in mortality rate.

4. Conclusions

Relative abundance of Niantic River winter flounder spawners as measured by otter trawl CPUE and absolute abundance estimates calculated using the Jolly model are highly correlated and appear to be reasonably accurate. These data have provided information useful in assessing the current status of this stock, which has been highly exploited by the fisheries as well as subject to CWIS effects at MNPS. Estimates of annual egg production resulting from the spawner surveys are key inputs to a methodology determining annual larval production loss due to entrainment. These values, in turn, are used with an impact assessment model to project future population abundance (Lorda et al., 2000). The long time-series of abundance and life history data have also proven useful to resource agencies charged with managing this species (Howell et al., 1992).

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