Aquaculture Research, 2005, **36,** 1374–1383 doi: 10.1111/j.1365-2109.2005.01355.x

Determining an optimal release site for juvenile winter flounder *Pseudopleuronectes americanus* (Walbaum) in the Great Bay Estuary, NH, USA

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Abstract

One of the main elements in developing an optimal release strategy for an enhancement effort is to evaluate and select release sites that will support growth and survival of newly released, cultured fish. Three potential release sites (New Castle (NC), Broad Cove (BC) and Oyster River (OR)) in the Great Bay Estuary, NH, USA were evaluated for pilot-scale releases of winter flounder (*Pseudopleuronectes americanus* Walbaum). Cultured juvenile flounder were placed in cages at each of the three sites. Sites were evaluated based on growth and survival of the fish in relation to water temperature, prey availability and sediment composition. Fish grew faster in the two upper estuarine sites BC (0.54 mm day^{-1}) and OR (0.56 mm day^{-1}) than at the site at the mouth of the estuary (NC = 0.37 mm day^{-1}). Fish survival (44–53%) and water temperature (17.8–19.7 °C) did not vary between sites. Benthic samples showed that prey was available to, and eaten by, the flounder. Sediment composition was the main difference between the three sites, with one site (NC) characterized by gravel whereas the other two sites were sandy. These results corroborate other studies showing the importance of sediment quality for the distribution of flatfish populations. From these results, we can confidently eliminate NC as a potential release area and recommend that sandy sites are better for stocking cultured juvenile winter flounder than gravely sites.

Keywords: winter flounder, sediment, cultured fish, enhancement, release site

Introduction

Recent declines of many marine species have caused a renewed interest in marine fish stock enhancement (Danielssen, Howell & Moksness 1994; Blankenship & Leber 1995), a potentially useful tool to boost declining natural populations when used in conjunction with proper resource management. Advances in culture technology now allow large numbers of juvenile fish to be produced, there is a wide array of marking techniques available, there is generally a much greater understanding of the fish's ecological requirements, and there are more sophisticated sampling techniques with which to measure survival and growth of the released individuals. However, in many stock enhancement programmes, initial survival rates of newly released cultured fish are low (Svåsand & Kristiansen 1990; Pitman & Gutreuter 1993; Iglesias & Rodríguez-Ojea 1994; Leber & Arce 1996; Tsukamoto, Masuda, Kuwada & Uchida 1997; Tanaka, Seikai, Yamamoto & Furuta 1998), and therefore, techniques to minimize this early mortality are critical. Because stocking cultured fish is not a simple task, Folkvord, Blom, Dragesund, Johannessen, Nakken & Naevdal (1994) and Blankenship and Leber (1995) compiled a list of the central issues associated with developing and evaluating stock enhancement programmes.

Identifying optimal release sites is one of the main criteria in developing an effective stocking strategy for juvenile marine fish (Blankenship & Leber 1995; Yamashita & Yamada 1999). Temperature, abundance of food and absence of predators all are critical parameters to consider when selecting optimal release habitats (Gibson 1994). Releases should be matched

to areas with high prey availability and at a time when there is the increased opportunity of encountering prey (Folkvord *et al.* 1994; Masuda & Tsukamoto 1998; Yamashita & Yamada 1999). Appropriate habitat also is necessary in the release site to offer protection and refuge from predators and to increase post-release survival (Olla, Davis & Ryer 1998). Factors such as presence or absence of micro- and macroalgae (Wennhage & Pihl 1994), sediment particle size and color (Yamashita & Yamada 1999), physical structures for refuge from predators, and currents should be categorized. For flatfish cryptic behaviour, substrate is especially important (Fairchild & Howell 2004). Selection of poor release sites could diminish the effectiveness of a stocking programme by reducing survival and distribution of released fish.

Dispersion paradigms often are linked to the quality of the release site. Generally, the more favourable the release site, the less dispersion there is. For example, when juvenile turbot (*Scophthalmus maximus* L.) were stocked into Danish coastal areas with high prey productivity, they maintained relatively high site fidelity (Støttrup, Lehmann & Nicolajsen 1998). Similar results have been documented for cultured striped mullet (*Mugil cephalus* L.) in Hawaii (Leber & Lee 1997), Japanese flounder (*Paralichthys olivaceus* Temminck & Schlegel) (Tominga & Watanabe 1998) and for Atlantic cod (*Gadus morhua* L.) (Svåsand & Kristiansen 1990). However, Pacific threadfin (*Polydactylus sexfilis* Cuvier & Valenciennes) were highly sensitive to release sites in Hawaiian bays and showed higher dispersion from sites depending on size and season of release (Leber, Brennan & Arce 1998). Likewise in Spain, the location of recaptured turbot varied drastically based on release sites (Iglesías & Rodríguez-Ojea 1994).

Prior to a full-fledged stocking effort, experimental studies should be conducted to evaluate the effectiveness of the proposed release strategies (Blankenship & Leber 1995). Proposed release sites should be surveyed by collecting information on abundance of prey and predators, habitat type and physical conditions (Tsukamoto, Kuwada, Uchida, Masuda & Sakakura 1999). In this manner, small-scale releases and studies can illuminate potential problems, and adaptive management (Leber 1999) then can be employed to alter and improve the release techniques.

For discrete, short-term flatfish studies, *in situ* cages can be useful tools. Sogard (1992), Phelan, Manderson, Stoner & Bejda (2000) and Manderson, Phelan, Meise, Stehlik, Bejda, Pessutti, Arlen, Draxler & Stoner (2002) have employed *in situ* cages to study juvenile winter flounder (*Pseudopleuronectes americanus*) growth within a New Jersey (USA) estuary. *In situ* cages also have been used in a North Carolina (USA) estuary to examine critical nursery habitats (Guindon & Miller 1995), food availability and growth (Kamermans, Guindon & Miller 1995; Kellison, Eggleston, Taylor & Burke 2003) of southern flounder (*P. lethostigma* Jordan & Gilbert). However, as noted by Kamermans *et al.* (1995), cages must be used with caution as they can introduce some, and often unknown, bias to the study. For example, cages isolate the fish to one area that may contain sub-optimal properties and restrict their movements. For winter flounder that take advantage of tidal cycles to move in and out of the intertidal zone to forage (Tyler 1971), caging may adversely affect their growth and survival. Cages also may disrupt the sediment, affecting benthic organism populations and possibly, reduce the movement of prey into the cages.

Following this rationale of experimental field studies, three potential release sites in the Great Bay Estuary, NH, USA were evaluated for pilot-scale releases of winter flounder. Cultured juvenile flounder were placed in *in situ* cages at each of the three sites. Sites were evaluated based on growth and survival of the fish in relation to water temperature, prey availability and sediment composition.

Materials and methods

Three possible release locations (Fig. 1) were selected for study in the Great Bay Estuary System, NH. One

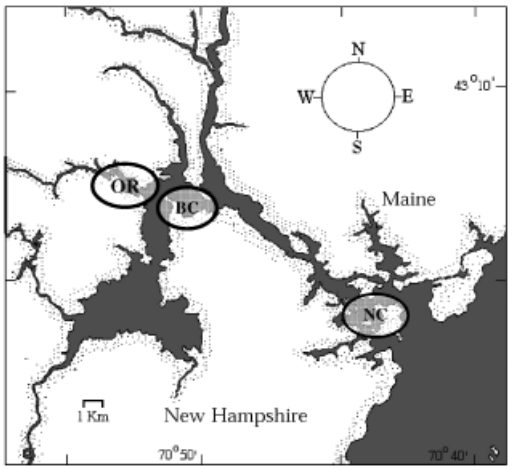

Figure 1 Three potential release sites in Great Bay Estuary, NH evaluated for winter flounder stock enhancement. NC is located to the west of Great Island in New Castle, NH; BC is Broad Cove in Newington, NH and OR is a cove in the Oyster River, Durham, NH, USA.

site, New Castle (NC), was located on the west side of Great Island, closest to the coastal terminus of the estuary. The other two sites, Broad Cove (BC) and Oyster River (OR), were located in the middle portion of the estuary. All sites were chosen based upon their physical and biological characteristics. Preliminary sampling suggested that good juvenile winter flounder habitats existed at each site. All sites were in small coves ($\sim$ 100 m across) with some muddy-sand substrate present, and were bounded by deep channels (2–3 m) that tend to hold fish in the shallower coves (Saucerman & Deegan 1991). Preliminary sampling showed adequate food items and the presence of wild juvenile winter flounder.

The field experiment was conducted from 7 July to 25 August 1999, using nine cages as the experimental units at each site, for a total of 27 cages. The 1 m^3 open-bottom cages, designed and built specifically for young-of-year (YOY) winter flounder by the National Marine Fisheries Service, Milford, Connecticut Laboratory, were constructed of a welded steel and wood frame with nylon mesh sides and a removable top. Along the bottom edge, 15 cm vertical steel plates extended into the substrate to prevent fish from escaping, while still allowing them to feed on the benthos, and prevented predators from entering. Cages were placed in the field 1 month prior to the onset of the experiment to ensure that any disturbances to the benthic community caused by positioning the cages in the substrate had time to recover. To verify they were securely set in the sediment, the bottom edges of the cages were examined using SCUBA. Immediately prior to stocking, the contents of the cages were seined to remove any potential predators such as sand shrimp (*Crangon septemspinosa* Say) and green crabs (*Carcinus maenas* L.). A data logger (Onset Computer, Pocasset, MA, USA) was attached to the base of one cage at each site to record bottom water temperature every 36 min.

Tagging

Cultured winter flounder were reared at the University of New Hampshire's Coastal Marine Laboratory from a wild caught broodstock (per methodology in Fairchild 1998). All fish were differentially color tagged with Visible Implant Fluorescent Elastomer Tags (Northwest Marine Technology, Shaw Island, WA, USA) injected subcutaneously on the ventral side of the fish. Eleven percent of the tagged fish ($n = 15$) were held in the laboratory for the duration of the experiment to examine tag retention rates and associated mortality. Tagged fish were held in the laboratory for 48 h before placement into the experimental pens to monitor any tagging-induced stress and/or mortality.

Growth and survival

A total of 150 fish (mean = 35.6 $\pm$ 1.1 mm TL; 0.6 $\pm$ 0.1 g) were stocked into the cages (5 fish·cage^{-1}) on 7 July 1999. Sampling was conducted weekly at low tide, when the upper portions of the cages were exposed, by seining the contents of each. After a total of 10 seine attempts, it was assumed that all surviving fish were captured. Captured fish were measured to the nearest 0.1 cm, weighed on a portable, digital balance to the nearest 0.1 g, and returned to their respective cages. At the end of the 7-week experiment on 25 August 1999, all remaining fish were collected, final measurements were taken and survival data were calculated.

The mean length and weight of all recaptured fish were calculated for each pen weekly. Using these data, differences in mean growth rates between sites were examined by analyses of variance followed by Tukey's posterior test. Additionally, mean daily growth rates were calculated for fish at each site. Percent survival data were arcsine transformed (Zar 1996) and survival was determined based on the final number of recovered fish. Differences in survival between the three sites were tested with analysis of variance.

Prey availability

To track prey availability, initial and final core sediment samples were taken at the beginning and end of the study. On each occasion, one core from within and one from outside of each cage were taken with a coring tube (7 cm diameter) to a depth of 5 cm. Sediment samples were sieved through a 500 μm screen. The residue was fixed with 10% buffered formalin and dyed with Rose Bengal for a minimum of 24 h. Prey organisms were identified to lowest possible taxon, counted, wet weighed to the nearest 0.001 g, and preserved in isopropyl alcohol. To determine if principal prey items of juvenile winter flounder (as determined by Fairchild 1998) changed over time, least squares regression analyses were employed. Both numerical abundance and the biomass of prey organisms in the sediment samples were used.

An additional core sample was taken from within each cage to determine the grain size composition of the substrate (Folk 1980). The mean percent gravel, sand, clay and silt at each site were calculated. Percent sediment composition data were arcsine transformed (Zar 1996). Differences in particle sizes between the three sites were tested with analyses of variance followed by Tukey's posterior tests.

Results

Tagging

Of the 15 tagged fish retained in the laboratory, none lost their tags, and none died during the 7-week course of the experiment. All fish recovered from the pens were identified by their tags.

Growth and survival

Over the course of the 7 weeks, all fish grew both in length (Fig. 2) and weight (Fig. 3). Fish from the upper estuarine sites (BC and OR) were significantly longer ($P \leq 0.001$) and heavier ($P < 0.001$) than fish from the site at the mouth of the estuary (NC) from weeks 2 to 7. Mean daily growth rates at NC, BC and OR were 0.37, 0.54 and 0.56 mm day^{-1} respectively. Seventy of the 135 fish (52%) were not recovered at the end of the experiment. Percentages lost were similar at the three sites (44% at NC, 49% at BC and 53% at OR). Based on final numbers of recaptured fish, there were no differences in survival ($P = 0.80$) between fish at the three sites.

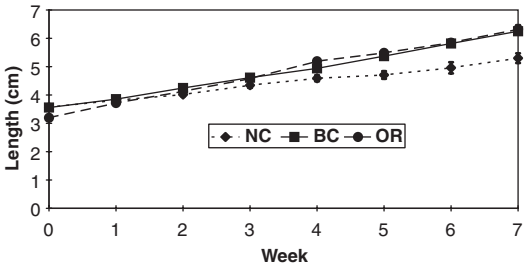

Figure 2 Mean growth (± 1 SEM) in length of cultured winter flounder held in pens at the three sites.

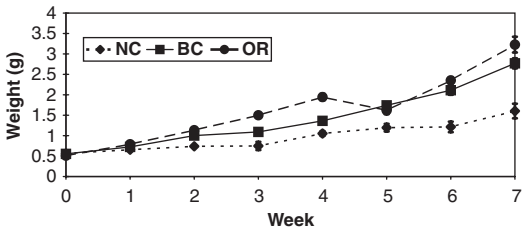

Figure 3 Mean growth (± 1 SEM) in weight of cultured winter flounder held in cages at the three sites.

Temperature

Mean bottom water temperatures were 17.8, 18.4 and 19.7 °C for NC, BC and OR, respectively, and were not statistically different ($P > 0.05$). NC bottom water temperature ranged from 11.3 to 25.2 °C, BC from 13.3 to 24.0 °C and OR from 10.6 to 26.7 °C.

Prey availability

A total of 54 sediment samples were examined to determine if fish grazed down the available benthic food supply within the cages. The five primary prey items examined were oribiniidaes, nematodes, amphipods, cumaceans and bivalves. Regression results show that the food items decreased over time inside the cages (Table 1). Within the cages at NC, only cumacean abundance decreased during the experiment. At BC, cumacean numerical abundance and biomass both decreased, nematode and amphipod biomass decreased, and oribiniidae numerical abundance decreased over time. In the OR cages, bivalve numerical abundance and biomass decreased. No decreases in numerical abundance or biomass of these five prey groups were observed in the cores collected outside of the cages.

Sediment composition

Sediment composition analyses revealed that significant differences existed between sites (Fig. 4). The NC site, primarily composed of two elements (sand = 54.5% and gravel = 43.5%), contained more gravel ($P < 0.001$) than the other two sites. Both BC and OR were sandier ($P = 0.002$) than NC, and consisted of 88.6% and 90.4% sand respectively. All sites contained small amounts of silt ($\leq$ 3.3%) and clay ($\leq$ 1.6%).

Discussion

Growth

Individual juvenile winter flounder show variable growth rates (Pearcy 1962; Sogard 1992; Witting

Table 1 Biomass and numerical abundance of the five primary prey types available to *Pseudopleuronectes americanus* inside and outside of the pens at each of the three sites

	NC				BC				OR			
	Inside		Outside		Inside		Outside		Inside		Outside	
	Slope	*P*-value	Slope	*P*-value	Slope	*P*-value	Slope	*P*-value	Slope	*P*-value	Slope	*P*-value
Biomass												
Oribiniidae	0.0008	0.7981	0.0002	0.9491	−0.0009	0.7722	−0.0011	0.1521	0.0009	0.7776	−0.0022	0.5331
Nematode	0.0000	0.3322	−0.0001	0.2293	−0.0001	**0.0121**	0.0000	0.1501	0.0000	0.1501	–	–
Amphipoda	−0.0002	0.1186	−0.0001	0.1065	−0.0012	**0.0376**	−0.0020	0.1401	0.0009	0.4392	0.0006	0.2807
Cumacea	−0.0002	0.1328	0.0001	0.4344	−0.0002	**0.0167**	−0.0001	0.0851	−0.0002	0.2232	0.0001	0.2070
Bivalvia	0.0000	0.3322	−0.0001	0.3838	0.0000	0.8090	0.0135	0.4071	−0.0005	**0.0299**	−0.0008	0.1236
Numerical abundance												
Oribiniidae	0.0476	0.5899	0.3651	0.1698	−0.3333	**0.0499**	−0.0476	0.6938	−0.1111	0.4345	−0.0317	0.8744
Nematode	−0.0635	0.3322	−0.1111	0.1927	−0.2063	0.1092	−0.0635	0.1501	−0.0635	0.1501	–	–
Amphipoda	−1.0476	0.0948	−0.7619	0.1009	−0.4921	0.0983	−1.4127	0.2207	−0.1270	0.0519	0.0000	1.0000
Cumacea	−0.3016	**0.0403**	0.0317	0.8568	−0.2063	**0.0193**	−0.0635	0.0851	−0.2381	0.1114	0.0476	0.1765
Bivalvia	−0.0317	0.3322	0.0000	1.0000	0.0000	1.0000	−0.4127	0.3861	−0.1429	**0.0375**	−0.1111	0.1137

Bolded *P*-values denote significant decreases ($P < 0.05$) in biomass or abundance of prey items based on least squares regression analyses. NC, New Castle; BC, Broad Cove; OR, Oyster River.

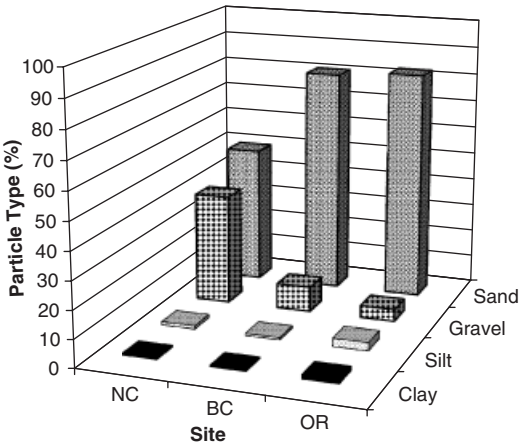

Figure 4 Sediment composition of benthic cores taken at each of the three sites. Mean percent particle type was calculated for gravel, sand, silt and clay.

1995; Phelan *et al.* 2000; Sogard, Able & Hagan 2001; Meise, Johnson, Stehlik, Manderson & Shaheen 2003) and this may be due, in part, to localized differences in habitat (Sogard 1992; Sogard *et al.* 2001; Manderson *et al.* 2002; Meise *et al.* 2003). In this study, growth was higher at BC and OR indicating that local site conditions varied enough to affect growth. In New Jersey estuaries, post-settlement winter flounder growth has been well studied and correlated to habitat and site. In Sogard *et al.* (2001) study, local site conditions affected juvenile winter flounder growth more than large-scale climatic forces. In both Manderson *et al.* (2002) and Meise *et al.* (2003) studies, temperature had the greatest influence on the growth rate of wild juvenile winter flounder, however, Manderson *et al.* (2002) found that there were many more factors, both spatially and temporally, that influenced fish growth in the estuary. These complex results reinforce the importance of characterizing potential release sites for optimizing growth in cultured fish.

In this study, fish growth (0.37–0.56 mm day^{-1}) was within the range of growth rates previously reported in other juvenile winter flounder field studies (0.28–0.35 mm day^{-1}, Pearcy 1962; 0.23–0.47 mm day^{-1}, Witting 1995; 0.36–1.44 mm day^{-1}, Sogard *et al.* 2001; 0.25–1.91 mm day^{-1}, Meise *et al.* 2003) and other cage studies (0–0.95 mm day^{-1}, Sogard 1992; 0–0.69 mm day^{-1}, Phelan *et al.* 2000; 0–0.9 mm day^{-1}, Manderson *et al.* 2002). This was surprising considering that two main differences exist between these previous studies and this one: (1) captured wild flounder were used rather than cultured fish; and (2) experiments were conducted in warmer mid-Atlantic (Connecticut, New Jersey and North Carolina) estuaries where fish growth is typically faster (Klein-MacPhee 1978). The growth rates in our study even surpassed a previous caging experiment using cultured winter flounder in New Hampshire (Fairchild 1998). In that study, a mean growth rate of only 0.06 mm day^{-1} was observed at an area near NC.

Little published information exists on estuarine Gulf of Maine winter flounder populations or on the growth rates of juvenile cultured winter flounder older than 60 days post hatch (dph). Chambers, Leggett & Brown (1988) demonstrated that at a mean temperature of 4.9 °C, cultured fish grew 0.145 mm day^{-1} from age 70 to 231 dph. In our laboratory, cultured winter flounder growth rates have ranged from 0.13 to as high as 1.26 mm day^{-1} for fish between the ages of 41 and 172 dph (E. A. Fairchild, unpublished data).

During the study period, the density of caged fish was 4000–5000 times higher than observed in natural winter flounder populations at the three sites (Fairchild 2002). While the caged fish densities of 5 m^{-2} may seem exorbitantly high compared with 0.1–0.25 wild fish 100 m^{-2}, this amount was used to ensure that adequate statistical analyses were possible. These inflated densities, however, did not seem to affect fish growth. Like Sogard's (1992) study, growth trends for length and weight were synchronous during the 7 weeks with the exception of weight data from NC at week 5. This decrease in weight was most likely because of sampling error rather than actual loss in fish biomass.

The slow initial growth of all fish can be attributed to an acclimation period. Upon release into the wild, cultured fish require an acclimation period to recover from the stresses associated with transportation and stocking (Wallin & Van Den Avyle 1995; Sulikowski, Fairchild, Rennels, Howell & Tsang 2005), to adjust to their new environment (Tsukamoto *et al.* 1999), hone their survival skills (Olla, Davis & Schreck 1992) and begin to forage efficiently (Nordeide & Salvanes 1991; Yamashita & Yamada 1999). In the case of winter flounder, the fish require a period of 2 days to sharpen their burial skills (Fairchild & Howell 2004) and at least 4 days to commence feeding (E. A. Fairchild, unpublished data).

Survival

There was a noticeable loss of fish from the cages. We believe our data do not accurately reflect the ability of the fish to survive at the site but rather the ineffectiveness of the cages at excluding predators. Some of the cages had holes in the mesh at the end of the experiment through which fish could have escaped or predators could have entered and consumed the fish. Although our survival results were biased because of cage failure, they do serve to emphasize the importance of predation in any stocking programme, and the importance of predator distribution and abundance surveys in proposed release sites.

Temperature

Winter flounder are eurythermal and can tolerate a wide range of temperatures (Pearcy 1962; Casterlin & Reynolds 1982). Although several studies have shown that growth is temperature dependent (Frame 1973; Laurence 1975), this relationship does not explain the growth differences between fish at NC and at the upper estuarine sites. No temperature differences were seen between these three sites during the course of this experiment suggesting that other parameters affected fish growth in this study.

Prey availability

Food was not a limiting factor at any of the sites in this study. At NC and OR there were small changes in biomass and numerical abundance of prey items within the cages, yet all fish grew over the 7 weeks. This suggests that as the fish were consuming orbiniidae, nematodes, amphipods, cumaceans and bivalves, recruitment to the benthos was occurring, resulting in a steady state. At BC where prey biomass declines were observed, the fish consumed the prey faster than it could recruit. However, based on good fish growth at this site, food was not a limiting factor. In fact, amphipod surveys taken simultaneously in the same areas showed that, on average, amphipods were more abundant at BC than at either of the other sites (Fairchild 2002). It could be that the BC fish were in a superior physiological state and were better able to feed than their counterparts in the other sites.

Two main factors may have influenced the prey analysis results. First, the core samples may not have been representative of actual prey abundances, because of the patchy distribution of benthic organisms (Ivlev 1961). Second, the pens themselves may have altered the initial prey densities as Sogard (1992) found in her caged winter flounder experiment. Because disturbances can cause rapid temporal changes to invertebrate communities in soft substratum (Choat 1982), the pens in this study were placed in the field 1 month prior to the beginning of the experiment to allow time for the infauna to adjust. However, as the magnitude of the change to the benthos was unknown (as a result of both pen placement and core sampling), the effects on the fish's diet can only be surmised. In addition, the pens may have

altered the light and sediment, which in turn, may have modified the settlement of potential flounder prey (Choat 1982).

Two schools of thought exist on the importance of food concentration and flatfish distribution. The first and older school of thought supports a high correlation between prey availability and juvenile fish distribution. Field studies have shown that plaice (*Pleuronectes platessa* L.) settle in food-rich areas (Zijlstra, Dapper & Witte 1982) and laboratory studies have shown that food supply affects the small-scale distribution of juvenile plaice (Wennhage & Gibson 1998). The second, and more widely accepted, school of thought is that substrate composition (which is indirectly related to prey availability) is the primary factor affecting flounder distribution. Through extensive field surveys, this has been shown for many flatfish including juvenile flathead sole (*Hippoglossoides elassodon* Jordan & Gilbert) and rock sole (*P. bilineatus* Bloch) (Abookire & Norcross 1998), plaice (*P. platessa* L.) (Pihl, Modin & Wennhage 2000), sole (*Solea solea* L.) (Rogers 1992) and yellowtail flounder (*Limanda ferruginea* Storer) (Walsh 1992). Most recently, research by Wanat (2002) indicates that amphipod and juvenile winter flounder abundance are not correlated in Great Bay Estuary, NH and, therefore, amphipod abundance may not be a critical element to mapping suitable winter flounder habitat.

In other cage studies, Kamermans *et al.* (1995) showed that prey density was not critical to juvenile southern flounder growth in a North Carolina estuary. Because of these results, they hypothesized that food abundance does not predict flounder distribution. Sogard (1992) found that winter flounder growth differences were not correlated to prey densities inside a caged experiment. On the contrary, she suggested a relationship existed between flounder growth and temperature and substrate. Manderson *et al.* (2002) corroborated this hypothesis by demonstrating that sediment characteristics were more influential on winter flounder growth than prey densities using generalized additive modeling. Our study further supports the hypothesis that flounder distribution is not necessarily correlated to habitats with high prey availability. Winter flounder growth was highest at the upper estuarine BC and OR sites despite low amphipod densities at OR.

For an enhancement effort, however, it would be unwise to ignore the importance of prey abundance in choosing an optimal release site. Other stock enhancement programmes have attributed low post-release survival to low prey availability. As food availability is the primary factor influencing growth rate in juvenile Japanese flounder (Fujii & Noguchi 1996), the presence of suitable prey in the days immediately after a release may be critical to cultured fish's survival, especially if their feeding ability is inferior to that of the wild flounder (Koshiishi, Itano & Hirota 1991).

Sediment composition

Obvious differences in sediment composition were seen between NC and the other two sites. NC was characterized as 'gravely' whereas BC and OR were characterized as 'sandy'. It is well known that juvenile flatfish prefer smaller sediment grain sizes (Tanda 1990; Moles & Norcross 1995; Gibson & Robb 2000) because of smaller body size, and this trend holds true for juvenile winter flounder too. Juvenile winter flounder prefer sandy rather than coarser or finer substrates. When given a choice, YOY always select fine-grained sediments (Phelan *et al.* 2000; Fairchild & Howell 2004). Manderson, Phelan, Stoner & Hilbert (2000) showed in laboratory studies that winter flounder < 50 mm were not capable of complete burial in gravel. As the mean size of the fish at the beginning of the study was only 36 mm, it is likely that the flounder could not bury at NC. Increased energy expenditure from unsuccessful burial attempts and position maintenance above the substrate during periods of high currents may have contributed to their lower growth rates. In this and Sogard's (1992) winter flounder caging studies, higher growth rates were observed in sandier areas.

Sediment composition is also a critical component for flounder crypsis. By burying into sandy substrates, flatfish become camouflaged to both prey and predators. However, burial is not the most effective survival skill in some predator–prey relationships when YOY winter flounder are prey (Manderson *et al.* 1999; Fairchild & Howell 2000; Manderson *et al.* 2000). In encounters with summer flounder (*P. dentatus* L.) as predators, sediment size did not affect survival (Manderson *et al.* 2000) although it was postulated that this effect may be transitory and that refuge by burial would augment survival as the winter flounder grew larger.

Based on the results of this study, juvenile winter flounder growth is linked more closely to substrate than prey availability. Because of the poor growth performance of the fish and the gravely substrate, NC can be eliminated as a potential release site. No extreme differences in fish growth, water tempera-

ture, prey availability or substrate composition could be discerned between BC and OR from this experiment. Based on these findings, BC and OR are equally good sites for a pilot scale release of winter flounder, however, surveys of predator distribution and abundance should be incorporated into the release site study and small-scale pilot releases should be conducted to test release strategies. Once release sites for cultured flounder are established, other facets of the release strategy need to be incorporated such as the production of fit hatchery fish (Fairchild & Howell 2004) and the reduction in stress from tagging and stocking these fish (Sulikowski *et al.* 2005). More work is needed to address the other key issues (Folkvord *et al.* 1994; Blankenship & Leber 1995) associated with cultured winter flounder and the development of a successful stock enhancement programme.

Acknowledgments

The authors are indebted to G. Rice, G. Smith and M. Toran for all their help in the field and lab; to L. Ward and A. Harmon for their tutelage and assistance in analysing the sediment compositions; and to the National Marine Fisheries Service Milford Laboratory for their generosity in loaning us the pens. This research was supported by the UNH/UME Sea Grant College Program under grant number R/FMD-158. This is number 420 of Jackson Estuarine Laboratory Contribution Series.

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