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Inter-annual variation in the surplus prey production for stocking of Japanese flounder *Paralichthys olivaceus*

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ABSTRACT

Stocking hatchery fish into the wild should only be implemented at a level that can be sustained within the available food-based carrying capacity to avoid food resource competition with wild conspecifics. We constructed a simulation model to assess the growth of wild conspecifics under different magnitudes of hatchery fish releases, including no releases and actual release levels, and under different wild fish abundancies. Stocking of juvenile Japanese flounder *Paralichthys olivaceus* (approximately 70–110 mm TL) in Fukushima from 2003 to 2005 was analyzed. We monitored post-release changes in abundance of both cultured and wild juveniles and their prey (mysids). Our survey and modelled simulations revealed that the surplus prey production was sufficient to support the consumption of stocked and wild Japanese flounder (up to 150,000 individuals per site in 2003 and 2004), during which wild juveniles achieved nearly maximum growth rates. However, in 2005, during which a dominant year class of wild Japanese flounder occurred, the body size of wild juveniles was 49% smaller than the predicted size based on the maximum growth rates. This suggests that the food-based carrying capacity was reached in that year. Thus, it is important to evaluate the existing prey and wild juveniles levels and adjust the release accordingly every year.

1. Introduction

The release of hatchery reared fish is a fisheries management tool used for enhancing stocks (Leber et al., 1995; Masuda and Tsukamoto, 1998; Molony et al., 2003). For a responsible approach to stocking (Blankenship and Leber, 1995; Lorenzen et al., 2010), the magnitude of release should be determined based on the available carrying capacity for food and space (Støttrup, 2004; Taylor et al., 2005; Yamashita et al., 2006; Støttrup and Sparrevohn, 2007). However, this has rarely been considered in stock enhancement programs, probably owing to difficulties in estimating the available carrying capacity or in assessing the impact of stocking on the natural environment and ecosystems.

Recently, some approaches have been suggested to determine the maximum magnitude of release (Brennan et al., 2008; Smith et al., 2012; Taylor et al., 2013). Yamashita et al. (in press) constructed an ecophysiology-based simulation model to estimate the optimum magnitude of release into a given area for Japanese flounder *Paralichthys olivaceus* and concluded that the optimum magnitude of release at the stocking site is largely governed by the densities of wild counterparts and prey at the time of stocking. This result also suggests that the optimum magnitude of release varies greatly among years even at the same site if the abundance of wild juveniles and/or prey is highly variable. Juvenile Japanese flounder mainly consume mysids (Hirota et al., 1990; Yamada et al., 1998), and because of their simple prey utilization, they are suitable for studying the surplus productivity which is closely related to the optimum amount of release.

In Fukushima, northeastern Japan, Japanese flounder is one of the target species for stock enhancement, and a million hatchery-reared (HR) juveniles, approximately 100 mm total length (TL) have been released between 1996 and 2010, before stocking was suspended following the great earthquake and tsunami in March 2011. The Japanese flounder stock enhancement program in Fukushima was characterized by the following: (1) fishermen paid 5% of their earnings from Japanese flounder landings for juvenile production, (2) fishermen consented not to land fish smaller than 300 mm TL, to achieve high stocking effectiveness, and (3) the recapture rates of

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stocked fish by coastal fisheries were high (7–17%; Tomiyama et al., 2008a). The high recapture rates in Fukushima were attributed to high prey productivity and large nursery areas (Fujita et al., 1993). High densities of mysids (approximately 1.0 g m^{-2}) are observed in summer (Tomiyama et al., 2013). Moreover, the release strategies such as the release site (Fairchild et al., 2005; Wada et al., 2010), season (Tanaka et al., 2006; Wada et al., 2012), and size at release (Yamashita et al., 1994; Leber, 1995) are nearly optimal for stock enhancement of Japanese flounder in Fukushima (Tomiyama et al., 2008a, 2009). On the other hand, the density of wild juveniles varies among years, with dominant (exceptionally strong) year classes occurring every 5–10 years (Tomiyama et al., 2008a). The dominant year class of wild fish consumes large amounts of prey and exhausts the food-based carrying capacity. Thus, the surplus prey productivity available for consumption by released Japanese flounder is thought to be highly variable, and in turn, the number that can be released each year varies.

This study examines the inter-annual variability in the surplus prey production as a method of determining the supportable stocking level of HR Japanese flounder at a site off Fukushima. In this study, the surplus production was defined as the amount of mysid production minus that portion which was consumed by wild Japanese flounder and other predators. We evaluated the surplus prey production, based on the growth response of wild counterparts to the different magnitude of release of HR fish. We used three-year datasets with different release timing and different levels of wild juvenile occurrence including a dominant year class. A model simulation, modified from Yamashita et al. (in press), was run to assess how much of the production of mysids is used by wild and released Japanese flounder at a given temperature and to examine how the growth of wild juveniles responds to the variation in the magnitude of hatchery releases or variation in the abundance of prey. Furthermore, the maximum allowable magnitude of release (i.e. optimum stocking density) that does not reduce the growth of wild counterparts was estimated, according to Yamashita et al. (in press).

2. Materials and methods

2.1. Stock enhancement program and field survey

In Fukushima, a million hatchery-reared (HR) Japanese flounder have been released annually at nine coastal sandy sites with depths less than 10 m (Tomiyama et al., 2008a). One of these release sites (Site A: 37° 46′N, 141° 00′E; see Tomiyama et al., 2009) was selected for this study, where daytime post-release surveys were carried out from 2003 to 2005. This site (coastline of 1 km and 2.74 km distance between the depths of 3 m and 15 m) has been a nursery ground for wild Japanese flounder. The timing of settlement of wild juveniles and their amount of settlement are highly variable in this area among years (Tomiyama and Minami, 2015).

Conditions of stocking (timing, size at release, and magnitude) varied among the three years. In 2003, a setback in the juvenile production in Fukushima led to the release of 60,000 small juveniles (approximately 70 mm TL) in September, produced in another locality. The abundance of wild juveniles in Fukushima in this year was low (highest density of 6.5 individuals per 1000 m^2) and their settlement was delayed (settled in early September). In 2004 and 2005, juveniles were produced in Fukushima and 150,000 HR juveniles (approximately 100 mm) were released at the study site in July 2004 and September 2005. The abundance of wild juveniles in 2004 was low (highest density of 9.7 individuals per 1000 m^2) and their settlement slightly early (settled in late July), while in 2005 the abundance was extremely high (dominant year class; 180.6 individuals per 1000 m^2) and their settlement medium (settled in mid-August). Thus, the release of HR juveniles in 2004 preceded the settlement of wild juveniles.

Fish were collected during daytime. On every sampling day, a 2 m beam trawl with a 3.7 mm mesh was towed at a speed of 2 knots, conducting 2–6 hauls of 10 min duration, over sandy areas with depths between 4 and 15 m. The towing distance was calculated using the Differential Global Positioning System (DGPS). The post-release samplings were conducted for 2–5 times (dates) until 91 days after release (Table 1). Collected wild and HR juvenile Japanese flounder were transferred to the laboratory under chilled conditions for later measurements. Before the release, 47–90 HR juveniles were sampled to determine the initial size (length and weight) of released fish.

Mysids (prey) were collected by towing a 0.6 m wide sledge net (Hirota net) with a 0.7 mm mesh for 3 min at a speed of 1.5 knots, at depths around 7.5 m without replication. The collection was accompanied by the daytime fish collection. Samples were fixed with 10% formalin. The towing distance (approximately 100 m) was calculated using the differential GPS. Bottom water temperature was measured at a depth of 7 m during each survey using a portable salinity and temperature sensor (UC-78, Central Kagaku Corp.). Salinity was constant at around 33 and therefore was not used for the analyses.

Table 1
Summary of the 3-year field survey at the study site. Total length (TL: mm) and estimated number in the study area (2740 m × 1000 m) of wild and released Japanese flounder juveniles.

Date	Days after release	Wild			Released		
		N[a]	N in the area	TL (mm)[b]	N[a]	N in the area	TL (mm)[b]
2003							
Sep. 18	10	4	8227	29.3	120	208,903	61.4
Oct. 7	29	8	8426	65.8	4	6058	90.9
2004							
July 15	6	0			52	131,042	97.7
July 28	19	0			22	63,594	116.1
Aug. 18	40	3	5164	49.7	15	23,753	135.3
Sep. 16	69	7	26,639	99.4	4	15,222	180.1
Oct. 8	91	9	20,550	131.1	2	4567	181.4
2005							
Sep. 20	0		494,769	75.8			
Sep. 29	9	60	320,103	79.7	2	10,393	112.6
Oct. 6	16	124	366,242	92.0	1	2611	126.2
Oct. 13	23	94	365,748	86.1	0		
Oct. 26	36	41	147,108	100.5	0		

[a] Number of fish collected.
[b] Average value.

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