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Transport, distribution and growth of larval patches of Pacific bluefin tuna (*Thunnus orientalis*) in the northwestern Pacific Ocean

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Abstract : The objective of the present study is to provide a clearer understanding of the early life ecology of Pacific bluefin tuna (PBT), *Thunnus orientalis*, with respect to changes in the recruitment process in relation to environmental conditions for a basis for stock management in the northwestern Pacific Ocean. Seven high density larval populations (patches) of PBT were tracked with reference buoys, and repeated sampling was carried out at study sites in the northwestern Pacific Ocean for periods ranging from 28 to 171 hours between the months of May and June from 2004 to 2008. The feasibility of detecting and tracking larval patches as well as appropriate protocols for plankton net observation were determined, and larval transport and distribution were examined. Survival and growth were observed in order to develop a model for these characteristics in larval stage PBT. This document is brief summary of the previous studies.

Key words : larval distribution, larval patch, larval growth, *Thunnus orientalis*, northwestern Pacific Ocean

Introduction

Annual catch volume of Pacific bluefin tuna (PBT), *Thunnus orientalis*, fluctuates greatly, ranging from 9,000 to 35,000 metric tons (Fig. 1). Since the majority of catch volume consists of premature (non-adult, juvenile) fish (Abe *et al.* 2010), annual catches of PBT are influenced by recruitment variability, which has been shown to vary annually by factors of six to ten (Yamada *et al.*, 2006, MacCall and Teo 2011). Recruitment variability of marine fish species is believed to be adjusted during the early life stages, from fertilization to recruitment. Several previous studies regarding the mechanisms that affect recruitment variability have revealed that many factors act simultaneously in order to condition year classes of fish during their early life stages (e.g. Houde 2009). Factors that affect recruitment variability differ by species as well as by year within a given species, and may even differ between spawning events. Knowledge of PBT larval growth, mortality, advection and diffusion remains incomplete, and mechanisms of recruitment variability are poorly understood. PBT larvae have also been shown to react to biological (e.g. food, predation) and physical conditions (e.g. sea temperature, sea flow) during their early life stages (Satoh et al, 2008, Satoh 2010, Satoh 2013). In the above studies, identical larval populations (patches) were tracked, larvae and food organisms were collected, and oceanographic observations were made. These efforts were undertaken in order to develop a clearer understanding of the relationship between environmental conditions and larval growth

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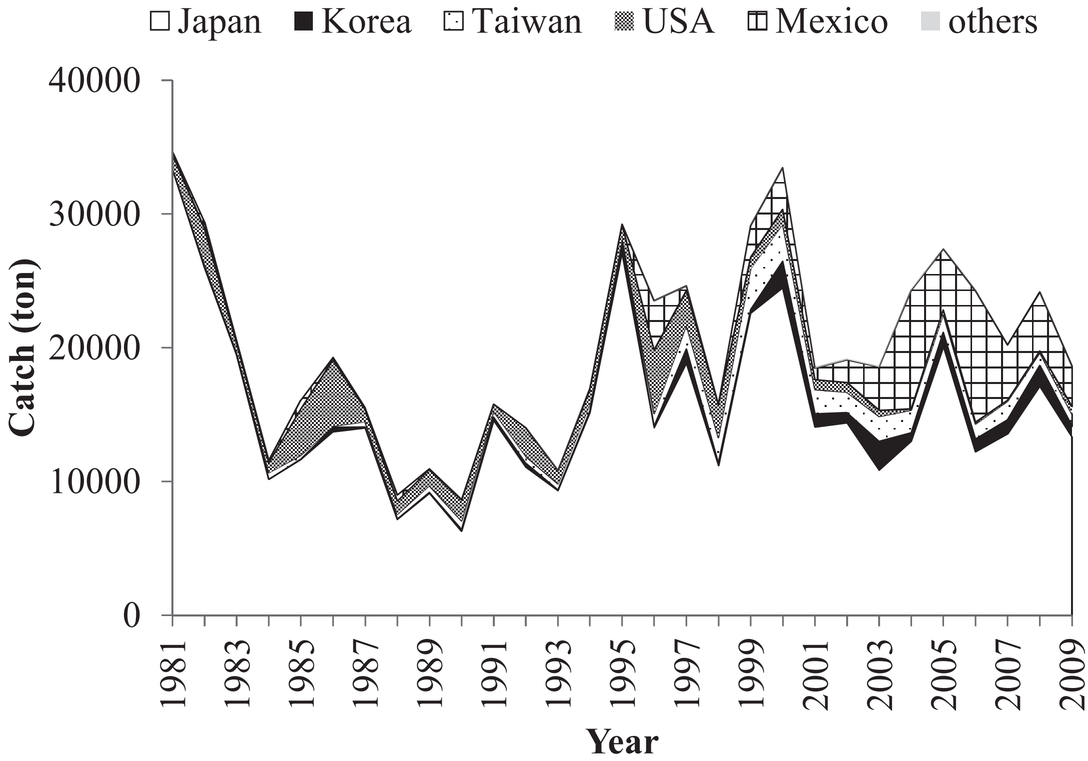

Fig. 1. Variations in annual catch of Pacific bluefin tuna by country (data from http://kokushi.job.affrc.go.jp /H22/ H22_04.pdf).

and survival in PBT (Davis *et al.*, 1990, Hearth 1992, Dower *et al.*, 2002).

The objective of the present study was to provide a clearer understanding of the early life ecology of PBT with respect to changes in the recruitment process in relation to environmental conditions, for a basis for stock management in the northwestern Pacific Ocean. The feasibility of detecting and tracking larval patches was determined, larval transport and distribution were studied and appropriate protocols for plankton net observation at sea were established. Larval survival and growth were determined in order to model these characteristics in larval stage PBT. This document is brief summary of the previous studies (Satoh et al, 2008, Satoh 2010, Satoh et al. 2013).

Materials and Methods

Sampling was carried out in the northwestern Pacific Ocean, off the coast of the Nansei Islands, Japan, during either May or the period from May to June from 2004 to 2008 (Table 1, Fig. 2). The detail of material and methods for the present study is described in previous studies (Satoh et al, 2008, Satoh 2010, Satoh et al. 2013).

Results and Discussion

Feasibility of detecting and tracking larval patches

Seven high density larval patches of PBT were tracked using reference buoys, and repeated samplings were carried out in the northwestern Pacific Ocean for periods of 28 to 171 hours between May and June from 2004 to 2008 (Fig. 2). Larval patches were detected after an average of 52 samplings (ranging from 6 to 80 total samples) carried out using a 2 m ring plankton net. In the present study, successive collection of larvae from the same patch was essential. Two pieces of evidence indicated that tracking of specific patches over periods of several days to a week had been successful: growth rates estimated from changes in mode of length frequency during each tracking event closely coincided with growth rates (0.25 to

Table 1. Mean temperature and salinity taken at a depth of 0 to 10 m, along with tracking duration, date, as well as start and end time and position. Patches 5 and 6 were not tracked.

Patch name	Tracking duration (hour)	Tracking start (detection)			Tracking end		
Patch 1	54	2004/05/15 23:37	22°N25.568´	124°E34.694´	2004/05/18 05:48	21°N57.908´	124°E46.185´
Patch 2	28	2004/06/01 23:52	26°N07.599´	129°E07.920´	2004/06/03 03:55	26°N07.139´	129°E20.813´
Patch 3	77	2005/06/02 04:47	24°N35.095´	126°E00.030´	2005/06/05 09:40	25°N09.925´	126°E40.373´
Patch 4	171	2006/05/22 02:01	23°N55.495´	124°E46.611´	2006/05/29 05:08	22°N33.514´	125°E20.008´
Patch 5	-	2006/06/13 19:56	24°N30.298´	127°E39.843´			
Patch 6	-	2006/06/14 03:04	24°N29.627´	128°E19.420´			
Patch 7	48	2007/05/17 03:45	22°N57.260´	124°E52.101´	2007/05/19 03:49	23°N17.639´	125°E32.774´
Patch 8	50	2007/05/28 00:54	25°N15.011´	124°E00.002´	2007/05/30 03:16	25°N11.378´	125°E58.647´
Patch 9	69	2008/05/24 03:06	24°N21.564´	127°E00.434´	2008/05/27 00:02	23°N55.079´	127°E36.004´

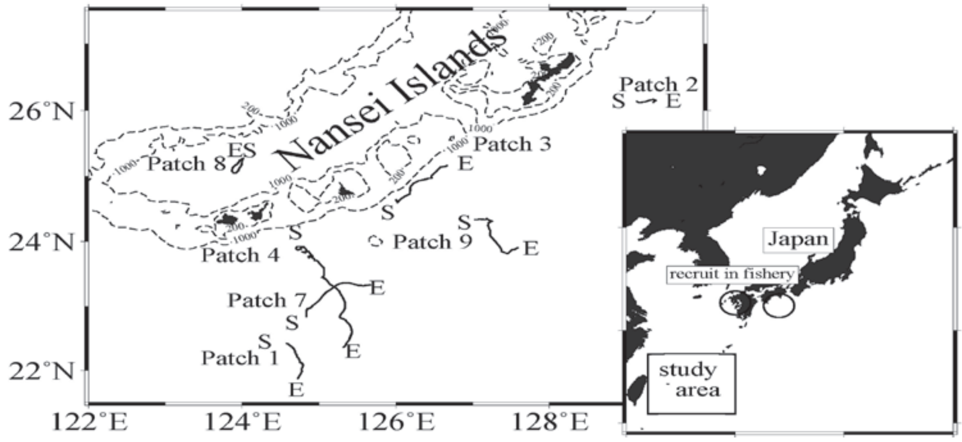

Fig. 2. Map of the study region off the coast of the Nansei Islands, Japan, indicating the 7 study sites and associated patch numbers, with buoy trajectories (solid lines) and tracking start (S) and end positions (E). Dashed lines represent 200 and 1000 m depth contours. large open circles: fishing grounds to which Pacific bluefin tuna are recruited.

0.85 mm day^{-1}, Table 2; Satoh 2010) determined through analysis of otolith daily rings; and buoy trajectories were consistent with the direction of sea currents. PBT larvae were collected from each patch except Patch 8 on the second day of tracking.

Larval transport and distribution

Patches were consisted of a number of cohorts (Fig. 3). Variogram analyses revealed that patches were typically spread over horizontal ranges of 15 km and that ranges of cohorts changed a little for periods of at least five days. Although detailed larval horizontal distributions changed in accordance with oceanographic conditions, larvae from a given assemblage have typically been restricted to the same 15 km range (Fig. 4; Satoh 2010). In order to detect patches and to determine the extent of their distributions, it was appropriate that plankton net tows should be employed every 7.5 km. Larvae were found to be distributed only within the surface mixed layer, and no discernible vertical diel movement was detected. Patches were entrained in mesoscale eddies (~100 to 500 km diameter) which propagated westward. Some mesoscale eddies in the study area have been known to coalesce with the Kuroshio Current, which meant that spawning areas and recruitment fishing grounds (Fig. 2) associated with patches examined in the present study were also linked to the flow of the Kuroshio. Results of previous study (Satoh 2010) suggested that cohorts possessed a stable spatial structure subsequent to fertilization (i.e. during advection, while entrained in mesoscale eddies). Therefore, it was suggested that

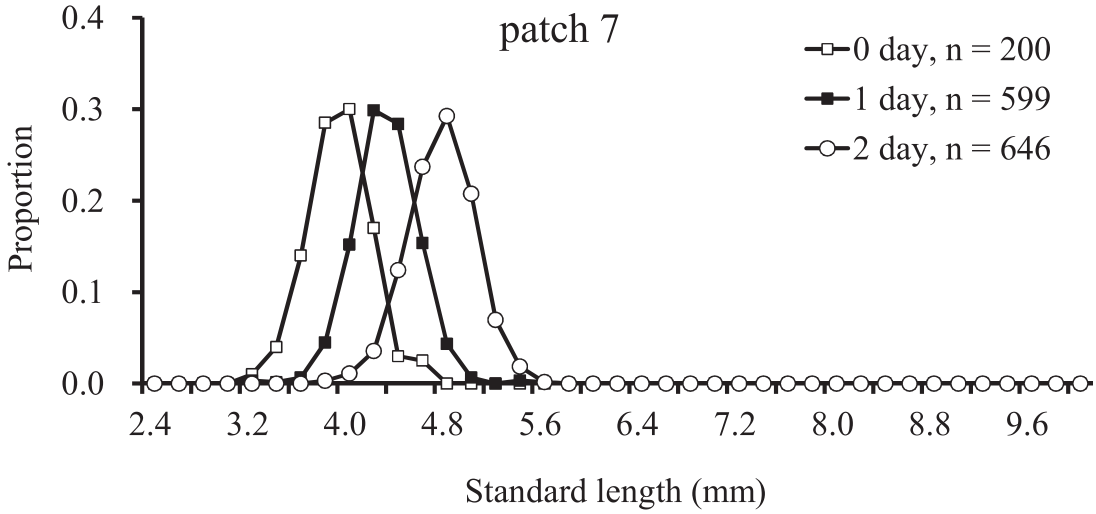

Fig. 3. Length frequency distribution for each day of tracking of patch 7. n: number of specimens measured.

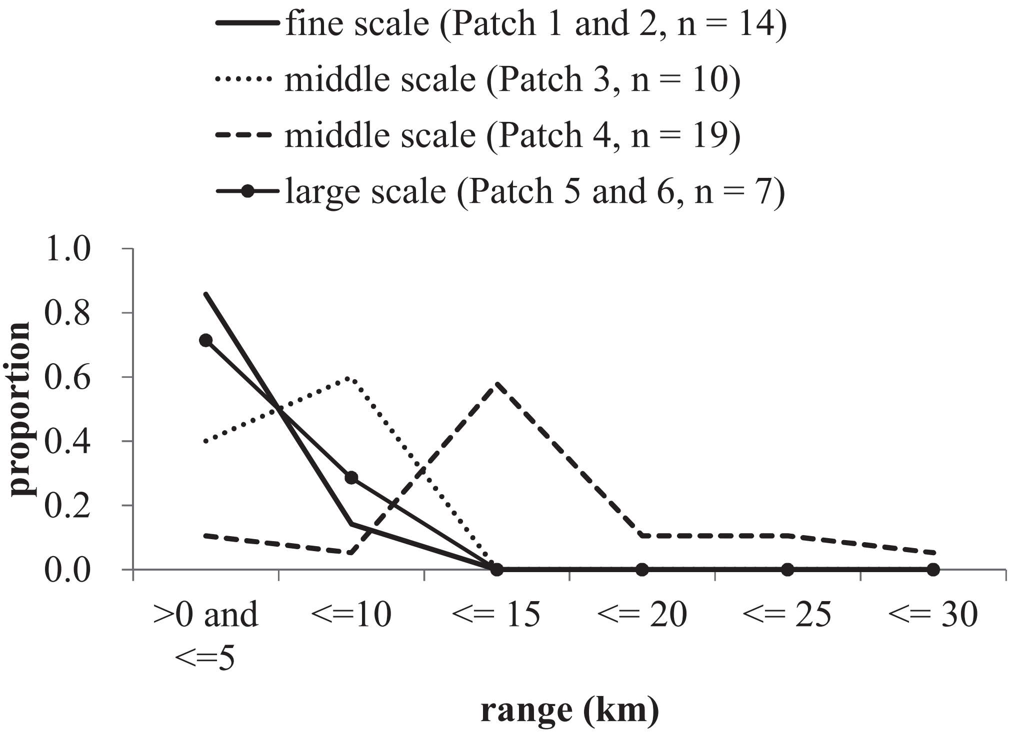

Fig. 4. Distribution of estimated range (variogram parameter that approximated horizontal size (radius) of patches) for each cohort. n: number of larvae in a given cohort.

spatial relationships between spawning events and mesoscale eddies were important to the recruitment process. Significant differences in length frequency distribution between day and night samplings clearly indicated that net avoidance had occurred. A significant difference in length frequency associated with different bongo net mesh apertures was also detected, which indicated that net extrusion had occurred within the 2 m ring net. These results indicated that raw larval density had to be corrected in order to obtain an accurate estimation of larval density (Satoh *et al.* 2008).

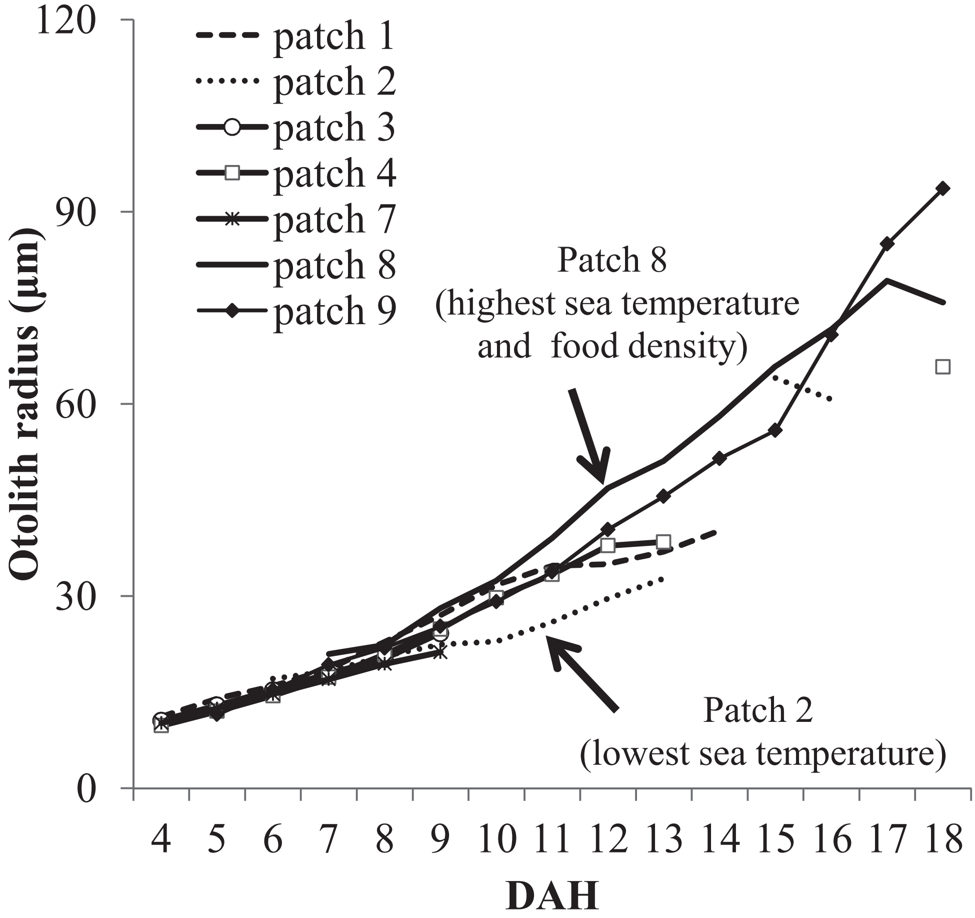

Fig. 5. Comparison of otolith radius (μm) among the patches.

Larval survival and growth

The growth model demonstrated that otolith radius (OR) of larval PBT was positively influenced by sea temperature, stratification parameters and food density, while growth rate of otoliths (GR) was positively influenced by sea temperature and food density (Fig. 5). Concrete regression growth models for both OR and GR were established (Satoh et al. 2013).

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