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Impacts of distribution of adult skipjack in tropical areas on the abundance of recruited juveniles in the water around Japan inferred from the framework of Individual Based Model with Dynamic Energy Budget Model

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Impacts of distribution of adult skipjack in tropical areas on the abundance of recruited juveniles in the water around Japan inferred from the framework of Individual Based Model based on Dynamic Energy Budget Model.

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Summary

• DEB-IBM (Individual Based Model (IBM) based on Dynamic Energy Budget (DEB) model) was applied to investigate migration of skipjack from their spawning grounds to off Japan area

• Particle tracking simulations were conducted following the preliminary study which well explained the body length composition of skipjack observed around off Japan with the same settings as follows; from November to February in subtropical and tropical areas as the spawning season and area, 50 m in depth as average vertical distribution of skipjack, and 1BLs^{-1} as average swimming speed.

• Initial locations of particles (i.e., assumed spawning grounds) were set to reflect fishery locations and amounts of purse seine and pole-and-line fisheries during the study period, and the number of particles reached to off Japan was compared with CPUE data of coastal trolling fishery of Japan.

Introduction

Understanding migration of skipjack (*Katsuwonus pelamis*) is important for stock assessments as it provides insights into connections among regions (e.g., Phillips *et al*., 2018), especially between regions defined in stock assessment frameworks. Regarding the western North Pacific Ocean, connections of skipjack populations between tropical and off Japan areas has been discussed in the context of distribution range contraction (Kiyofuji *et al*., 2015), and connections between these two regions have been indicated by model approaches including Individual based model (IBM) (Aoki *et al*., 2017, 2018, Senina *et al*., 2017).

To measure issues arising in the simulation study regarding how far the simulation can be realistic, Individual Based Model with Dynamic Energy Budget model (DEB-IBM) offers to use not only the track of particles, but also the fork length for more realistic estimation of skipjack movement by passing the water temperature and food environment data (Kooijman 2010, Jusup et al., 2011) obtained on the tracks of particles by IBM into the DEB to estimate growth that particles should achieve (Aoki *et al*., 2018). The fork length results of the DEB part can be compared with the observed body length composition, in other words, it is able to evaluate how realistic the track of a particle is in terms of the growth by this approach. In the previous study (Aoki *et al*., 2018), initial locations of particles (i.e., spawning grounds) were located uniformly in each grid ranging from 120–180°E and 20°S–20°N (1°×1°, 2400 particles in total), which still would not be so realistic. In fact, skipjack catch in tropical areas tends to be higher than that in subtropical areas (Williams and Reid, 2018), and this difference should be reflected in the initial locations of particles in the model for more precise simulation, instead of adopting uniform distribution.

In this document, catch locations of purse seine and pole-and-line fisheries are incorporated in the DEB-IBM model to determine initial locations of particles. Then, migration rate was recalculated through the years from 2002 to 2011. With the data prepared in the previous documents (for the period of 2002 to 2010, Aoki *et al*., 2018), one year update for 2011 was conducted, and effects of initial locations and numbers of particles weighted by catch data were evaluated by comparing the number of particles reached off Japan area (20°N) with Japanese coastal trolling fishery CPUE (Kiyofuji *et al*., 2014).

Materials and methods

Model outline

A model used for an analysis of particle tracking with weighting on the initial locations of particles by fishing ground information based on catch data of purse seine and pole-and-line fisheries consists of an Individual Based Model (IBM) combined with a Dynamic Energy Budget model (DEB, Kooijman 2010). As a comprehensive description of model settings would be lengthy and has been described in previous reports (Aoki *et al*., 2017, 2018), the model descriptions are briefly explained here. It should be noted that this report mainly focuses on the impact of parameters for the IBM parts.

Simulation setting

The IBM part was conducted assuming that fish migrate by passive transport and active swimming which was set to start at beginning of a juvenile stage. Swimming speed and depth were set to be one body length (BL)sec^{-1} and 50 m, respectively, based on the reports of previous analysis revealed that the body length composition in area off Japan was well explained with this setting in terms of growth (Aoki *et al*., 2017). The growth was estimated by the DEB part based on the environment data (food and temperature) along with the trajectories obtained from the particle tracking of the IBM. Direction of particle movement was defined by choosing the coolest grid among surroundings on a daily scale. Environmental data of ocean such as temperature, eastward and northward ocean currents at the depth of 50 m were obtained from the Hybrid coordinate ocean model (HYCOM) + Navy Coupled Ocean Data Assimilation (HYCOM + NCODA Global 1/12° Reanalysis; https://hycom.org/data/glbu0pt08/expt-19pt1).

we set a particle in each grid ranging from 120°E - 180°E and 20°S - 20°N (1°×1°, 2400 particles in total) as initial locations. It was conducted by assuming skipjack distribute uniformly in the western Pacific. Position of each particle was calculated every 3 hours. Release of particles started from November 1st of study year and another particle was added in each grid on the first day of every month until February based on historical larvae sampling research results (Kiyofuji *et al*., 2015). With the total of four release events per year, annual trends in the particle migration was explored through years from 2002 to 2011. In a case of landing of a particle on the shore, the simulation for the particle was terminated.

We chose the particles released in the northern hemisphere (0 to 20 °N) for this analysis to focus on the particle migration in the north western Pacific especially toward the area off Japan. The particle migration was calculated with consideration of recruitment, natural and fishing mortalities, and fish density estimated from fishing ground distribution recorded in catch data. Recruitment and natural and fishing mortalities were employed from the 2016 skipjack stock assessment (https://oceanfish.spc.int/en/ofpsection/sam/sam/213-skipjack-assessment-results#2016). The recruitment values in quarter 4 in region 2 and 3 of the 2016 skipjack stock assessment was used (Fig 1). An average by year and average by the target period of these values were used. In addition, natural and fishing mortalities were incorporated in the calculation of the particles to release. Natural mortality at age was obtained from the 2016 skipjack stock assessment (Fig. 2), and fishing mortality at age was defined as an average among regions in the period of 2002-2011 (Fig. 3).

Initial number of released particles weighted by fishery information

Number of particles to release was determined by weighting for each grid by using catch data of purse seine and pole-and-line fisheries available in the WCPFC website (https://www.wcpfc.int/node/4648). The fishery data is aggregated by year, month, and spatial grids of 5°×5° latitude/longitude. Fishery locations in the catch data were extracted for the months of November, December, January, and February through (1) the years from 2002 to 2011 to match the release period of particles (Fig. 4), and (2) the overall years from 1950 to 2017 (Fig. 5). Note that the grid scale is different between the particle tracking setting and the WCPFC catch data, so the same catch data was applied for the particle tracking grids within a grid of catch data. In order to focus on the weighing effects, the recruitment and natural and fishing mortalities used for the simulation in case (2) were averaged value by the studied period.

Result & Discussion

Annual trend in particle migration rate for simple particle tracking to off Japan area

When particles were set uniformly through target areas, about 70-80% of particles that reached off Japan area (>20°N) were from subtropical area of 10-20°N (Fig. 6). This is simply based on differences in travel distance between subtropical and tropical area toward off Japan. Though migration rate from tropical area was relatively low, particles reached the area through calculated years of 2002-2011. The ratio of the particles from area of 0-5°N fluctuated around 10 to 20% among years.

Effect of initial number of particles regarding natural and fishing mortalities and weighting based on catch amount

For further discussion of particle migration in more realistic numbers among areas, the number of particles released from each grid was set by considering recruitment, natural and fishing mortalities, and annual catch within a grid. Number of particles reached off Japan area was largely fluctuated among years (Fig. 7 right). Apparently, fishing mortality largely affects the number of particles compared to the scenario using the natural mortality alone (Fig. 7). The total amount of particles in each year was apparently influenced by annual recruitment differences; relatively few particles reached off Japan in 2007 and 2010 when the recruitment was estimated to be in low levels. In addition to the influence, the fishery ground also had a certain degree of influence on the results. The significantly few particles reached off Japan area in 2010, and it was caused by almost none catch reported in subtropical area (Fig. 4). It is not realistic to regard that there were no skipjack in subtropical area in certain years, thus weighing simply based on the amount of annual catch should lead to substantial underestimation.

As a next step, fishery ground distribution was used to weight the particle numbers. Along with the use of historical values of catch data (Fig. 5), the averaged recruit (and natural/fishing mortalities) of the target years was also used for this calculation. Particles weighted with historical fishery ground distribution showed stable migration from subtropical to off Japan area (Fig. 8). Contrastingly, the number of particles from tropical area was highly fluctuated between years. Since averaged recruitment (natural and fishing mortalities) was used for this calculation, the fluctuation in the number of particles reached from tropical was mainly induced by the distance that particles should migrate; the further a particle should travel, the more affected by physiological features of ocean such as currents and eddies. It also should be noted that the weighing method included zero-catch data in the subtropical region to calculate an average amount of catch in a grid, thus it might cause an underestimation in the area.

Comparison with JPPL logbook

For the last step, trends between the number of particles reached off Japan and CPUE of troll fishery targeting skipjack were compared (Fig. 9). Though the simulated period (released year of 2002-2011 corresponding to reached year in off Japan of 2004-2013) was shorter than the available period of CPUE data (1993-2018), fluctuations between 2004 and 2010 showed a similar trend. Contrastingly, the simulation indicated a large number of particles reached off Japan while the CPUE was in a low level. The CPUE was calculated based on the reported catch of trolling fishery operated in excessively coastal areas of Wakayama prefecture, Japan. Thus, the CPUE may represent not only migrated individuals but also the variated distribution of fishery ground from year to year. In fact, it was reported that skipjack flexibly change their migration routes according to distributions of cold and warm water masses (Kiyofuji *et al.*, 2019). The relationship between the simulated number of particles reached to off Japan area and the fishery ground distributions from year to year should be evaluated by using the more accurate current models such as the FRA-ROMS ocean forecast system for area around Japan (http://fm.dc.affrc.go.jp/fra-roms/) with high reproducibility of local currents and stream near Japan.

Conclusion & Future work

This round of DEB-IBM model shows the influence of parameters such as recruitment, natural and fishing mortalities, and distribution of actual fishing grounds. The number of particles considering recruitment, natural and fishing mortalities and weighted by catch gave the results that have similar trends to that of CPUE of coastal trolling fishery. Besides, the further away the initial location of the particles, the more fluctuation in the number of particles reached off Japan area. On the other hand, it should be noted that the simulated period is relatively short (about 10 years). For further discussion of the particle migration, longer periods of simulations are necessary. Besides, steepness of skipjack should be incorporated in future analyses in addition to weighing by the catch data.

References

Aoki, Y., Masujima, M., Kiyofuji, H. (2017). Skipjack migration in the western central Pacific Ocean estimated from the particle tracking simulation with dynamic energy budget model. WCPFC-SC13-2017/SA-IP-09.

Aoki, Y., Masujima, M., Kiyofuji, H. (2018). Annual trend in migration rate of skipjack from spawning grounds to off Japan. WCPFC-SC14-2018/SA-IP-05.

Jusup, M., Klanjscek, T., Matsuda, H., Kooijman, S. A. L. M. (2011). A full lifecycle bioenergetic model for bluefin tuna. Plos One 6(7): e21903.

Kiyofuji, H. Ashida, H. Sugimoto, M., Horii, Y., Okamoto, H. (2014). Abundance of skipjack migrating to the Pacific coastal water of Japan indicated by the Japanese coastal troll and pole-and-line CPUE. WCPFC-SC10-2014/SA-WP-10 Rev 1.

Kiyofuji, H., Ashida, H. and Satoh, H. (2015). Revisiting the spatial and seasonal distribution of tropical tuna larvae and their potential spawning area in the western central Pacific Ocean. WCPFC-SC11-2015/SA-IP-10.

Kiyofuji, H., Aoki, Y., Kinoshita, J., Okamoto, S., Masujima, M., Matsumoto, T., Fujioka, K., Ogata, R., Nakao, T., Sugimoto, N. and Kitagawa, T., (2019). Northward migration dynamics of skipjack tuna (Katsuwonus pelamis) associated with the lower thermal limit in the western Pacific Ocean. Progress in Oceanography, 175, pp.55-67.

Kooijman S.A.L.M. (2010). Dynamic energy budget theory for metabolic organization. Cambridge University Press. 017/SA-WP-07.

Phillips, J.S., Gupta, A.S., Senina, I., van Sebille, E., Lange, M., Lehodey, P., Hampton, J. and Nicol, S. (2018). An individual-based model of skipjack tuna (*Katsuwonus pelamis*) movement in the tropical Pacific ocean. *Progress in Oceanography*, *164*, pp.63-74.

Senina, I., Lehodey, P., Kiyofuji, H., Masujima, M., Hampton, J., Smith, N., Williams, P. (2017). Impacts of recent high catches of skipjack on fisheries on the margins of the WCPFC convention area. WCPFC-SC13-2017/SA-WP-07.

Williams, P., and Reid, C. (2018). Overview of Tuna Fisheries in the Western and Central Pacific Ocean, including Economic Conditions 2017. WCPFC-SC14-2018/GN-WP-01.

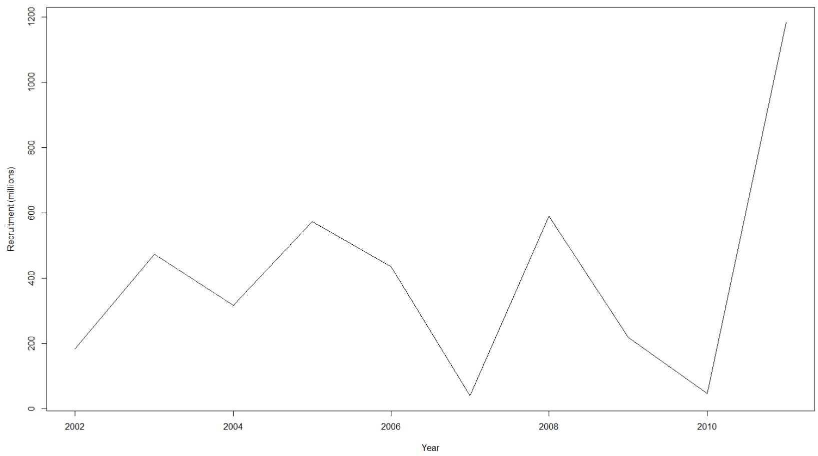

Figure 1. Recruitments for regions 2 & 3 in quarter 4 from the 2016 stock assessment.

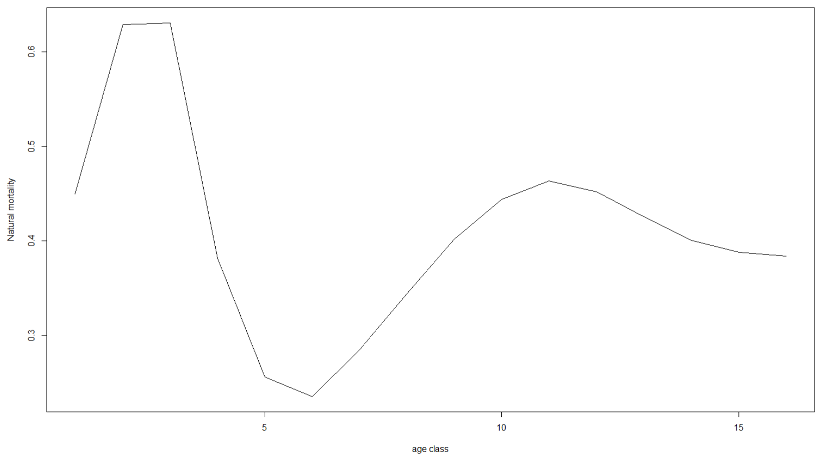

Figure 2. Natural mortality at age class from the 2016 stock assessment.

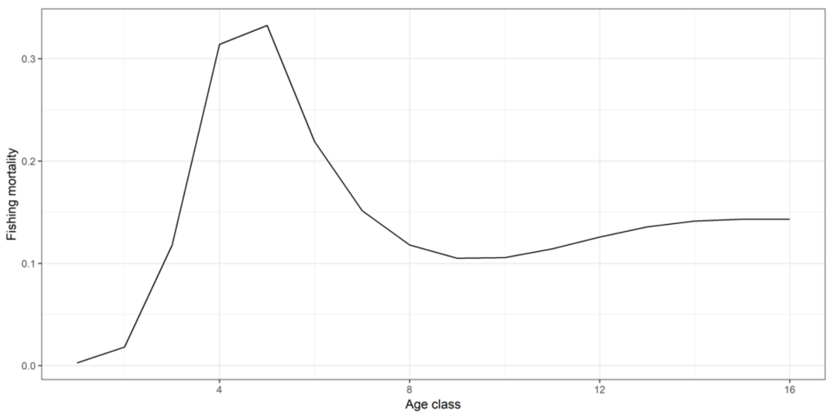

Figure 3. Averaged fishing mortality at age for all regions in the 2016 stock assessment.

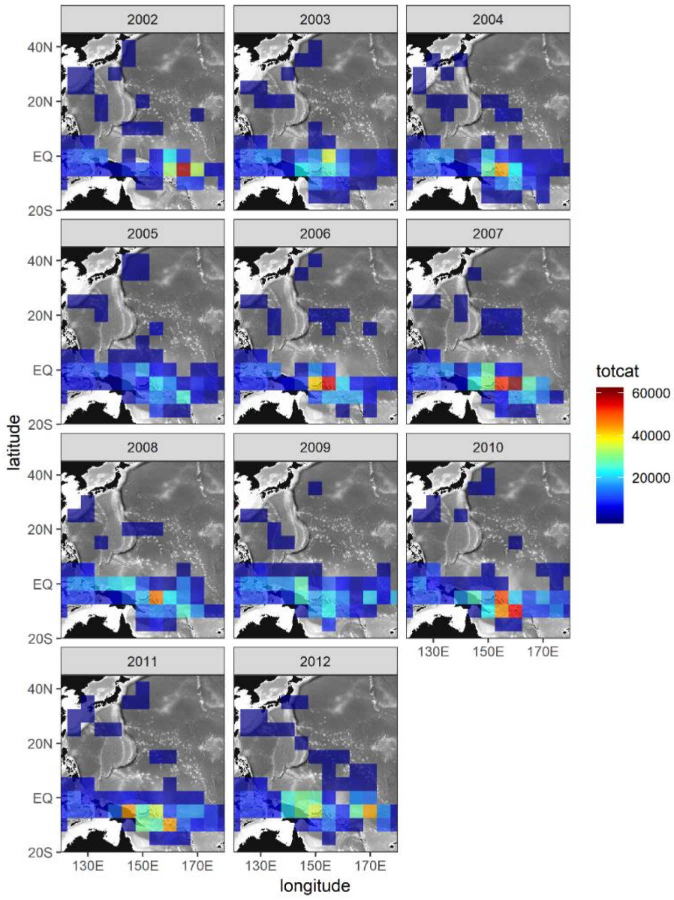

Figure 4. Total catch by purse seine and pole-and-line fisheries from November to February in the years from 2002 to 2012.

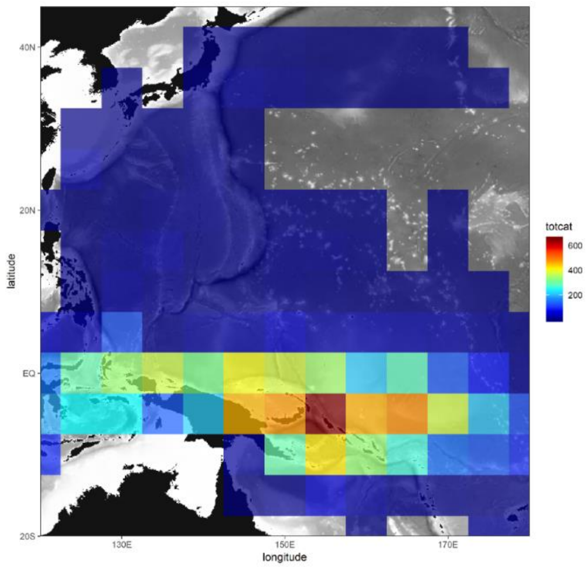

Figure 5. Fishery location of purse seine and pole-and-line fisheries from 1950 to 2017.

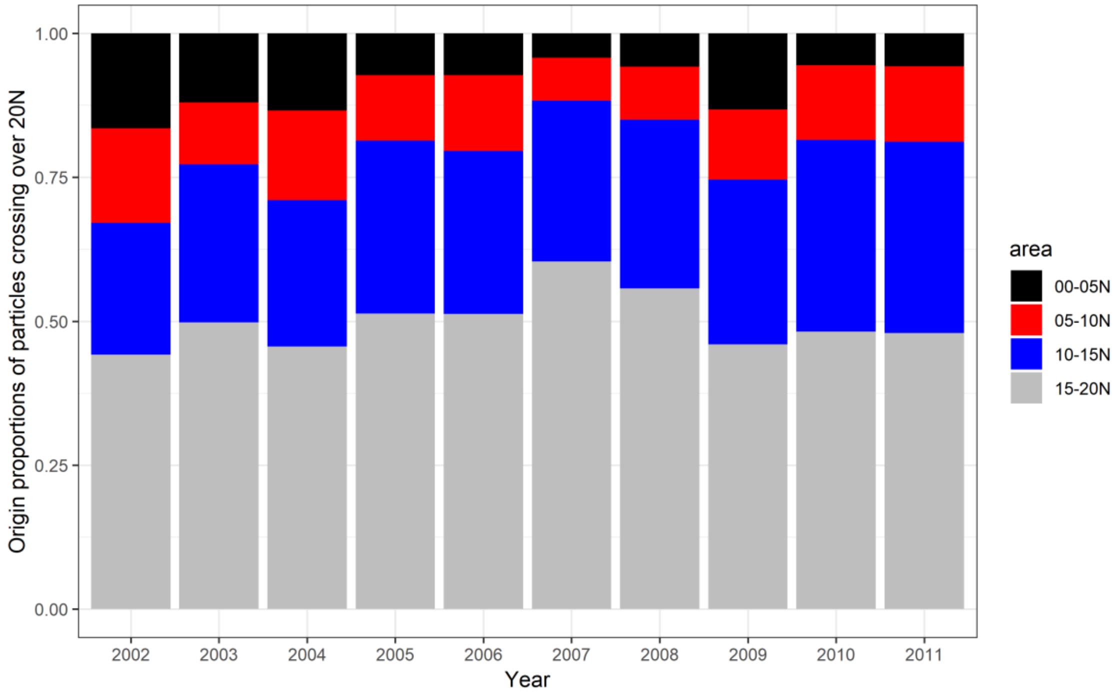

Figure 6. Proportion of particles migrated from released locations of 0 to 5°N, 5 to 10°N, 10 to 15°N, 15 to 20°N to off Japan area (>20°N) in the studied years from 2002 to 2011. Note that the proportions are calculated with a setting of uniform distribution of particles in the initial locations.

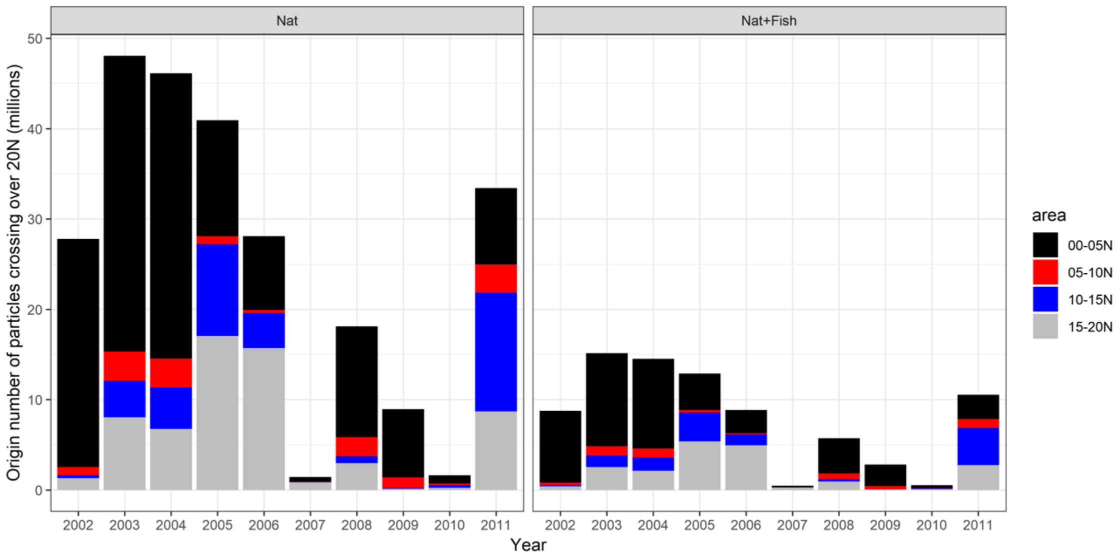

Figure 7. Number of particles migrated from the released locations of 0 to 5°N, 5 to 10°N, 10 to 15°N, 15 to 20°N that reached off Japan area (>20°N) with settings of natural mortality (left) and natural and fishing mortality (right). Initial locations were weighted by annual catch data, and annual recruitment of corresponding year was used for calculations.

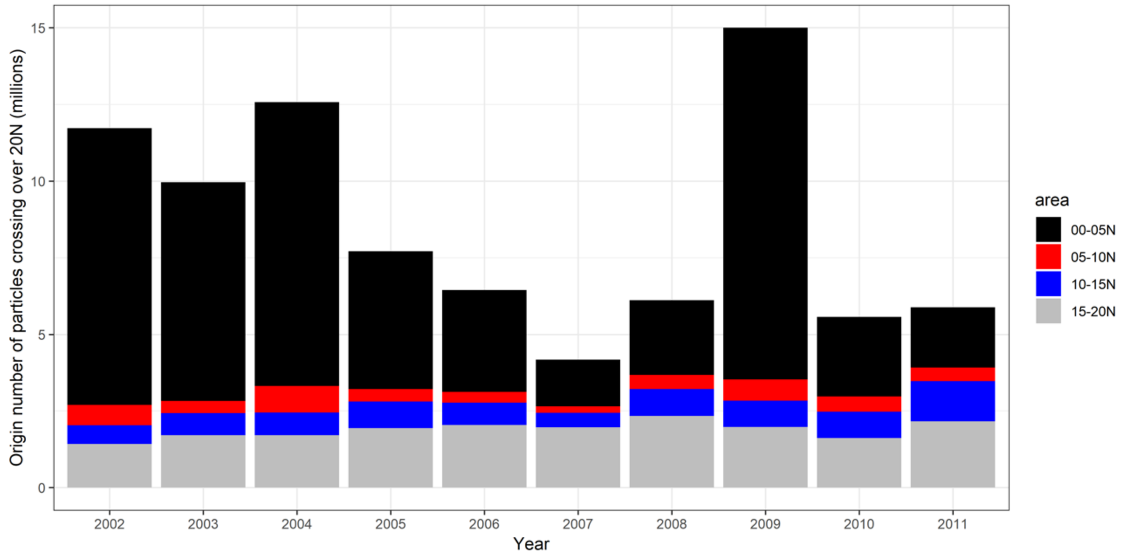

Figure 8. Number of particles migrated from the released locations of 0 to 5°N, 5 to 10°N, 10 to 15°N, 15 to 20°N that reached off Japan area (>20°N). It was calculated based on averaged recruitment form 2002 to 2011 considering natural and fishing mortalities with weighted number of particles in initial locations by catch data.

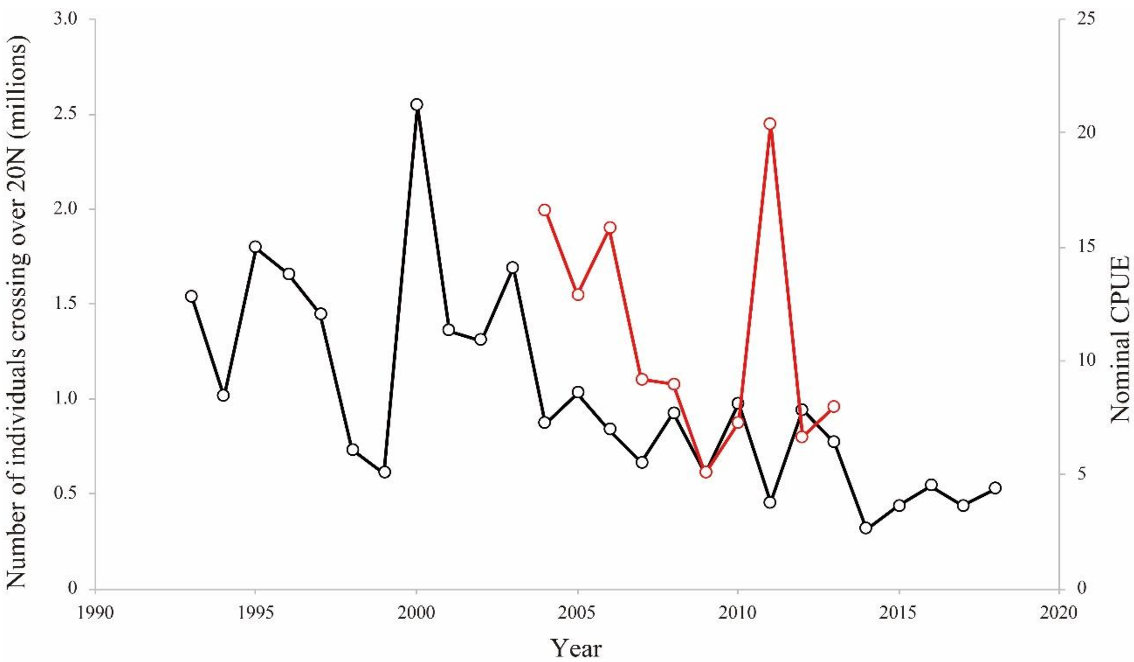

Figure 9. Number of particles crossing over 20°N (black line) toward north and nominal CPUE (red line) for skipjack in coastal area of Wakayama, Japan. Note that the number of particles were counted when calculations were terminated and compared with the same year of the CPUE data, thus the recorded year should differ from the released year.