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Preliminary investigation of the relationships between environmental conditions and landings of North Pacific giant octopus (*Enteroctopus dofleini*) at Minamikayabe, Hokkaido

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Abstract

Relationships between environmental factors and fluctuations in landings of North Pacific giant octopus (*Enteroctopus dofleini* Wülker, 1910) at Minamikayabe town, Hakodate city, Japan, during 1985-2016 were analyzed using regression analysis. Annual landings ranged between 165 and 403 tons, with an average of 273 tons. The relationship between landings and temperature was significant in 9 of the 24 months examined ; 7 of the 9 occurred in catches 3-4 years after the temperature was measured. The relationship between landings and salinity was significant in 4 of the 24 months examined ; all 4 occurred in landings 3-4 years after the salinity was measured. Rainfall showed no significant relationship with catch amounts. The results of the regression analyses suggest that landings of *E. dofleini* were related to ocean temperature, especially to temperatures 3-4 years before the landings occurred, presumably during the early part of the life cycle of the landed octopuses.

Key words : *Enteroctopus dofleini*, North Pacific giant octopus, Environmental factors, Catch abundance

Introduction

Cephalopod populations have increased globally since the 1950s (Doubleday et al., 2016). One possible reason is these ecologically and commercially important species may have benefited from changing environmental conditions. Cephalopods adapt quickly to such changes in large part because most species grow quickly, have short life spans and exhibit strong life-history plasticity. Annual variability in abundance is influenced by environmental variability (e.g., Pierce, 1995 ; Robin and Denis, 1999 ; Wang et al., 2003 ; Pierce et al., 2008 ; Rodhouse et al., 2014 ; Keller et al., 2017). In octopuses, catches of the common octopus (*Octopus vulgaris*) have been found to relate to sea surface temperatures (Balguerias et al., 2002 ; Sobrino et al., 2002 ; Vargas-Yanez et al., 2009 ; Caballero-Alfonso et al., 2010 ; Thiaw et al., 2011) and rainfall (Sobrino et al., 2002 ; Sonderblohm et al., 2014). In Alaska, density of the North Pacific giant octopus (*Enteroctopus dofleini* Wülker, 1910) has been found to correlate with winter sea surface temperature in the eastern Gulf of Alaska (Scheel, 2015).

E. dofleini is a large, muscular species distributed widely in the North Pacific from Japan (including the Sea of Okhotsk and Bering Sea) to Baja California, Mexico (Hartwick, 1983 ; Cosgrove and McDaniel, 2009 ; Sano, 2013 ; FAO, 2014). In Japan, it occurs along the Sea of Japan coast from Hokkaido to the Goto Islands, and along the Pacific coast to Sagami Bay or Suruga Bay (Mitsuhashi, 2003). In Hokkaido, it occurs along the continental shelf from the intertidal zone to around 200 m depth. Spawning is thought to occur around March-July (Mitsuhashi, 2003 ; Noro, 2012), and spawned eggs have been confirmed in the Sea of Japan, Pacific Ocean, and Sea of Okhotsk from May to December (Fukuda, 1995). In the Sea of Japan, hatching occurs in December-March (Hokkaidō-ritsu suisan shikenjo, 1995), and the planktonic paralarvae are thought to occur near the surface mainly from January to March, with first settling on the seafloor occurring in February. Its maximum lifespan is thought to be about 4-5 years (Noro, 2012).

In Japan, *E. dofleini* is fished mainly in Hokkaido and the Tohoku district (northern Honshu island), where it is an important coastal resource. In Hokkaido, annual catch amounts are about 10,000-20,000 t. To determine if catch amounts can be forecast based on environmental data, Noro (2012) analyzed sea surface temperatures and catches on the fishing ground near Tsugaru Strait and found significant positive correlations between the monthly average temperatures in August, September, and October, and catch amounts two

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years later. The objective of the present study was to conduct a similar exploratory analysis on a fishing ground in southern Hokkaido using temperature and salinity data at 0–80 m depths, and rainfall data.

Materials and methods

Fishery data

We analyzed monthly landing statistics from Minamikayabe town, Hakodate city, Hokkaido, during 1985–2016 collected by the Hakodate Fisheries Research Institute. The octopus fishery in the study area operates nearly year round using several gear types, including *takobako* (wooden boxes), *takokago* (trap nets), and *isari* (a lure attached to a float). The landing statistics combined catches from all gear types. Fishing effort data were not collected during the study period.

Environmental data

Temperature and salinity data were collected by the Hakodate Fisheries Research Institute during oceanographic surveys in 2000–2016 in most even–numbered months (i.e., February, April, June, August, October, and December). The data were collected at two stations (41.967°N, 141.003°E (about 5 km offshore) in 2000–2015, and 41.973°N, 141.383°E (about 21 km offshore) in 2015–2016) using a CTD at 5–m intervals between 0 and 80 m depths (Fig. 1).

Rainfall data collected monthly during 1985–2016 at Kakkumi, Minamikayabe town, were provided by the Japan Meteorological Agency.

Data analysis

The relationships between catch abundance and environmental parameters (temperature, salinity and rainfall) were examined using regression analysis. In the analyses, the dependent variable was landing amount, and the independent (explanatory) variables were the monthly value of each environmental parameter. In each sampling month, the environmental parameters were analyzed with the total annual landings 1, 2, 3, and 4 years after the parameters were measured. A similar analysis method was used by Noro (2012) for catch amounts of *E. dofleini* in Tsugaru Strait between Hokkaido and Honshu islands. We considered the relationship between a parameter and landing significant when the coefficient of determination (R^2) was $\geq$0.49 (Iwanaga et al., 2001).

Significant results from the regression analysis were further analyzed using stepwise regression. This resulted in a set of candidate models, which were compared used the cross validation test and an Akaike Information Criterion (*AIC*). For both stepwise regression and cross validation, we used Excel and R (R i386 3.1.1). The "best" selected model was then used to estimate landings during 2005–2015 (excluding 2006 and 2013 due to lack of temperature and salinity data in 2003 and 2010), which were compared to the actual landings.

Landing forecasts for 2017–2019

The objective of this study was to conduct an exploratory analysis of octopus landings at Minamikayabe and their relationships with environmental factors. Understanding such relationships can allow fisheries managers to forecast fisheries

Fig. 1. Hokkaido, Japan. Minamikayabe is the port where landing data were collected. Numbers indicate oceanographic sampling stations.

catches, so we concluded this study by using the best selected model to forecast landing amounts for 2017–2019.

Results

Landings

Annual landings at Minamikayabe during 1985–2016 ranged between 165 and 403 tons, with an average of 273 tons (Fig. 2). Landings were highest in summer and peaked in June (Fig. 3).

Relationships between landings and environmental conditions

Results of the analyses of landings and both temperature and salinity are shown in Table 1. The relationship between landings and temperature was significant in 9 of the 24 months examined. Seven of the 9 occurred in catches 3–4 years after the temperature was measured. The relationship between landings and salinity was significant in 4 of the 24 months examined ; all four occurred in landings 3–4 years after the salinity was measured. Rainfall showed no significant relationship with catch amounts.

Temperature and salinity were both related with landings at two sampling points : at 70 and 75 m depths in February three years before the landings (Figs. 4–5). Both regressions were positive. Data from these two depths in February were chosen for the subsequent regression analyses and catch forecasts.

The regression analyses of the data from these two depths resulted in the six models shown in Table 2. The results of cross validation and AIC to assess the model prediction performance both selected the following model as the best for predicting catch amounts :

$$C = 40.10 * T_{75} + 128.31 * S_{75} - 4{,}145.78$$

Where C is catch, T_{75} is temperature at 75 m depth three years before the landings, and S_{75} is salinity at 75 m depth three years before the landings.

Figure 6 compares actual catch amount and those estimated using this model during 2005–2015. All standardized residuals fall between –2 and +2, which is expected for an N (0.1) distribution.

Landing forecasts for 2017–2019

Landing forecasts using this model for 2017–2019 are shown in Figure 7. They suggest a drop in 2017, followed by increases to about 400 tons in 2019, which is near the maximum landing recorded during 1985–2015.

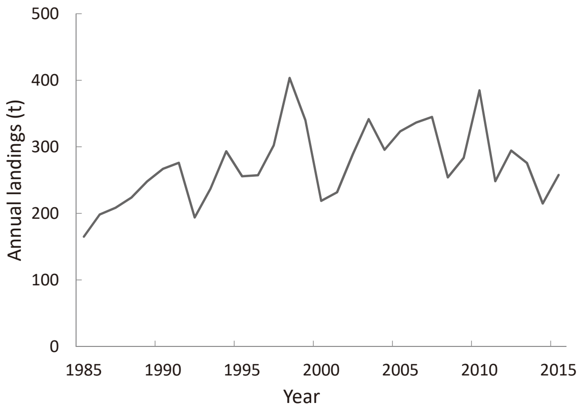

Fig. 2. Annual landings (t) of North Pacific giant octopus (*Enteroctopus dofleini*) at the Minamikayabe Fisheries Cooperative Association during 1985–2016.

Discussion

The results of our regression analyses suggest that landings of *E. dofleini* at our study site were related to ocean tempera-

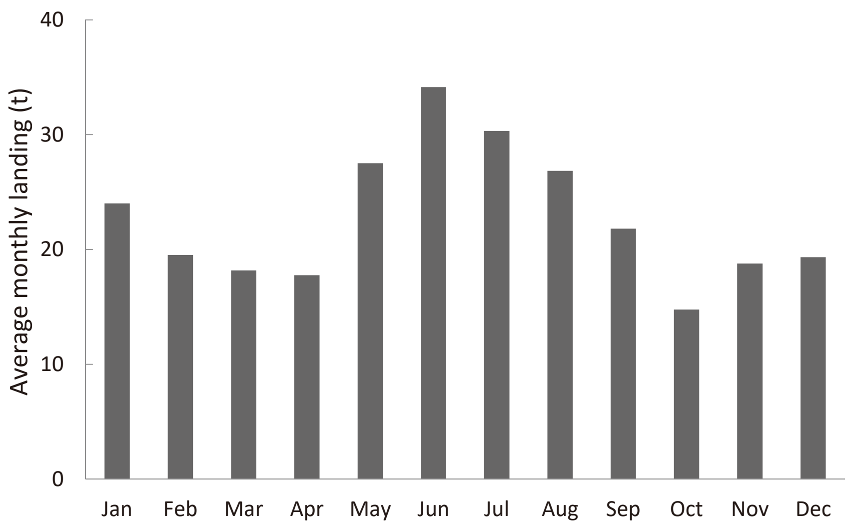

Fig. 3. Average monthly landings (t) of North Pacific giant octopus (*Enteroctopus dofleini*) at the Minamikayabe Fisheries Cooperative Association during 1985–2016.

Table 1. Results of regression analysis of catch abundance and environmental parameters (temperature and salinity) at 0–80 m depth. In each sampling month, the environmental parameters were analyzed with the total annual landings 1, 2, 3, and 4 years after the parameters were measured. Letters indicate significant relationships for temperature (T) and salinity (S).

Depth (m)	Annual catch 1 year later						Annual catch 2 years later						Annual catch 3 years later						Annual catch 4 years later					
	Feb	Apr	Jun	Aug	Oct	Dec	Feb	Apr	Jun	Aug	Oct	Dec	Feb	Apr	Jun	Aug	Oct	Dec	Feb	Apr	Jun	Aug	Oct	Dec
0																					S	T		
5			T															T			S	T		
10			T															T			S	T		
15			T																					
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45																								T
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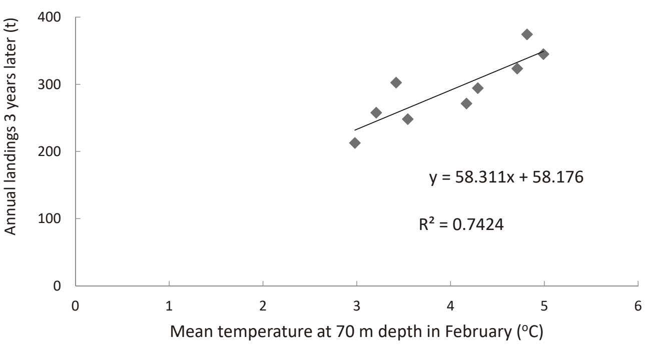
60													T				T							
65											T		T				T							S
70											T		T+S				T							S
75											T		T+S					S						S
80											T		S											S



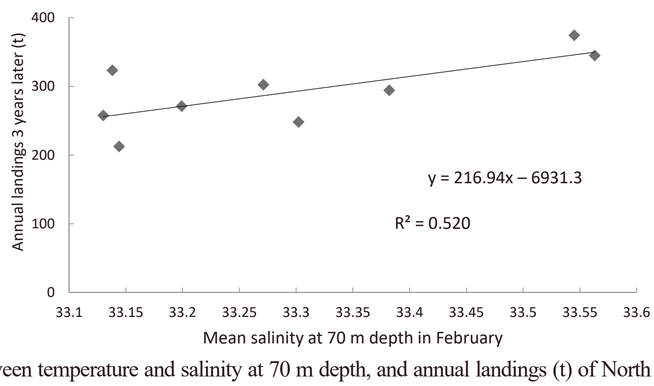


Fig. 4. Relationships between temperature and salinity at 70 m depth, and annual landings (t) of North Pacific giant octopus (*Enteroctopus dofleini*) three years later at the Minamikayabe Fisheries Cooperative Association.

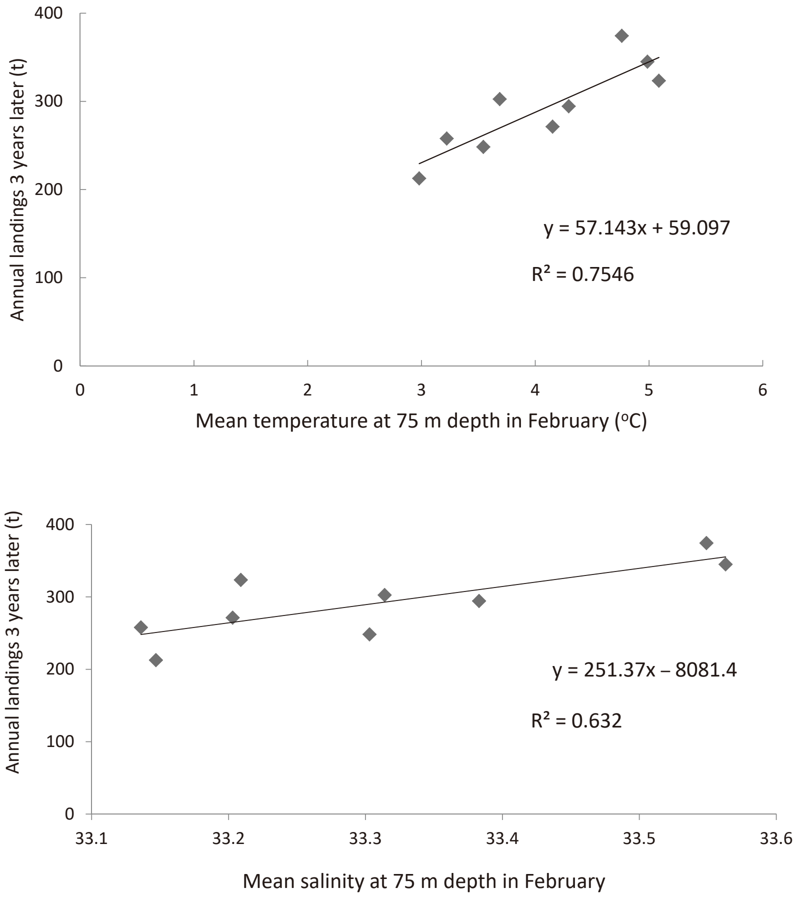


Fig. 5. Relationships between temperature and salinity at 75 m depth, and annual landings (t) of North Pacific giant octopus (*Enteroctopus dofleini*) three years later at the Minamikayabe Fisheries Cooperative Association.

Table 2. Models evaluated from regression analysis. Σ loss indicates results of cross validation. AIC : Akaika information criterion.

No	Model	Σ loss	AIC
1	$C=58.31*T_{70}+58.18$	8,487	61.37
2	$C=216.94*S_{70}-6931.34$	16,087	66.98
3	$C=57.14*T_{75}+59.10$	8,250	60.93
4	$C=251.37*S_{75}-8081.43$	11,771	64.58
5	$C=46.21*T_{70}+81.84*S_{70}-2618.14$	10,487	61.77
6	$C=40.10*T_{75}+128.31*S_{75}-4145.78$	5,965	58.38

C : Catch
T_{70} : Temperature at 70 m depth three years before catch
S_{70} : Salinity at 70 m depth three years before catch
T_{75} : Temperature at 75 m depth three years before catch
S_{75} : Salinity at 75 m depth three years before catch

ture, especially to temperatures 3–4 years before the landings occurred. Similar results were reported by Noro (2012), who examined sea surface temperature near Tsugaru Strait during 1980–2010 and found significant positive correlations between the monthly average temperatures in August, September, and October, and catch amounts two years later. In our study area, the minimum landing size for *E. dofleini* is 3 kg, and, while body weight is not a reliable indicator of age, this species usually reaches this size during the second or third year after hatching (Noro, 2012). This suggests that the temperatures 3–4 years before the landings would have occurred during the early part of the life cycle of the landed

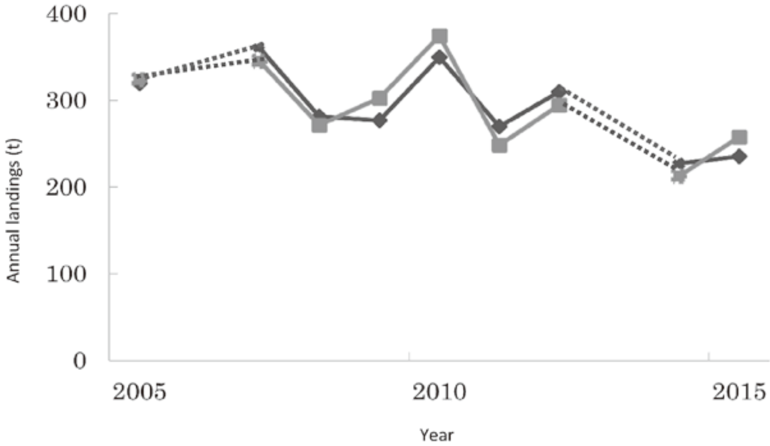


Fig. 6. Comparison of estimated landings of North Pacific giant octopus (*Enteroctopus dofleini*) using the model describe in the text and actual catches at the Minamikayabe Fisheries Cooperative Association during 2005–2015. Red : estimated catch ; blue : actual catch. No data shown for 2006 and 2013.

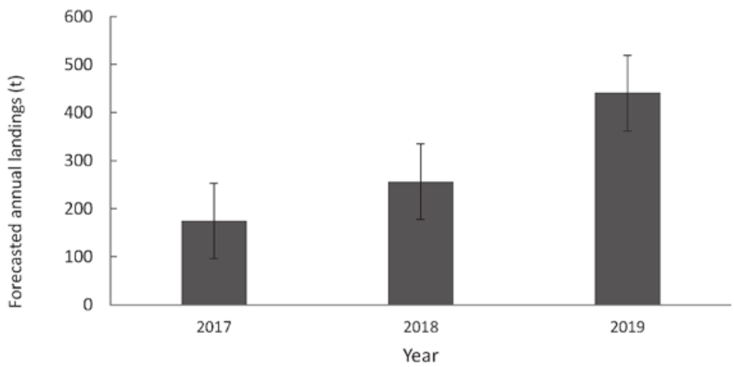


Fig. 7. Forecasted landings of North Pacific giant octopus (*Enteroctopus dofleini*) in 2017–2019 using the model described in the text. Error bars indicate standard deviations.

octopuses.

Information about *E. dofleini* egg masses in the field is limited, but in the Sea of Japan (Hokkaido) and Pacific coastal areas, eggs have been observed at 30–70 m depth (Mitsuhashi, 2003), and embryonic development is thought to last about six months (Sano, 2013). Landings were related with temperature below 25 m depth in February (3 and 4 years before the landings), August (3 years before), October (2 and 3 years before), and December (4 years before). Though the evidence here is not strong, temperatures experienced by developing embryos during these months may have affected the future landings.

Temperature could similarly have affected the planktonic paralarvae. Information about the distribution of paralarvae around Hokkaido is also limited, but they have been collected off East Hokkaido in June–July at 9–21 m depth (total lengths = 8–10 mm ; Yamashita and Torisawa, 1983). In Tsugaru Strait, they are thought to occur in surface waters from January to March (Noro, 2012). Our results suggest landings were related to water temperatures near the surface (0–20 m depth) in August (4 years before the landings) and in December (3 years before).

Monthly landings were found to increase in summer. As the sea surface temperature rises, *E. dofleini* moves offshore into deeper, cooler waters (Noro, 2012), so landings would be expected to decrease. But fishing effort for octopuses generally increases during summer as other fisheries in the area (e.g., for konbu (kelp), salmon, and walleye pollock) become less active.

Salinity, which varies less than temperature, showed a weaker relationship with landings. And rainfall, which affects salinity at the surface, showed no evidence of being related to landings. This differs from the results of studies of *Octopus vulgaris* by Sobrino et al. (2002) and Sonderblohm et al. (2014), who reported significant correlations with rainfall.

The forecasts from our best model suggest catches might increase during 2017–19, but we caution in the use of such forecasts until we have a better understanding of the ecology of the early life stages. Particularly important include determining where and at what depth both embryonic development and the planktonic paralarval stage occur. Without this basic information, it will not be possible to develop reliable models.

In conclusion, the results of this study do not prove that landing amounts are directly controlled by temperature, as temperature could be an indicator of some other factor influencing survival at early stages, such as prey abundance. But they do suggest that the two are related as has been reported in *O. vulgaris*. Octopus fisheries around the world are likely going to be significantly impacted by climate change (FAO, 2014), so a better understanding of how environmental conditions affect the abundance and distribution of octopuses will benefit both fishers and managers, especially as fisheries for invertebrates such as the cephalopods grow in importance (Anderson et al., 2011).

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