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ABSTRACT

Oceanographic conditions in the JARPNII survey area were study by using FRA-ROMS data. FRA-ROMS is an ocean forecast system developed by Fisheries Research Agency (FRA) based on Regional Ocean Modeling System (ROMS). Changes in area ($km^2$) of four water types (Oyashio, cold, warm and Kuroshio) by each month (April-September) in JARPNII survey area from 2000 to 2013 was investigated. There was no statistical significant trend for the area except the cold water in September. Negative values of annual mean the Pacific Decadal Oscillation (PDO) index were dominant in the period from 2000 to 2013. Generally, sea surface temperature in the western North Pacific is high in the negative phase of the PDO. The results of this study indicated that overall oceanographic conditions in the JARPNII survey area from 2000 to 2013 were relatively stable although year to year variations and spatial heterogeneity of distribution of water types were observed.

## INTRODUCTION

The second phase of the Japanese Whale Research Program under Special Permit in the North Pacific (JARPNII) has been conducted since 2000. The survey in the first two years (2000 and 2001) was conducted as a feasibility study and then it has been conducted as a full scale research since 2003. The survey area was set in the western North Pacific. Main target species of JARPNII are common minke (*Balaenoptera acutorostrata*), Bryde's (*B. edeni*), sei (*B. borealis*) and sperm (*Physeter microcephalus*) whales The southern, northern, eastern and western boundaries of the survey area were 35°N, the boundary of the economic exclusive zone (EEZ) claimed by countries other than Japan,170°E and the eastern coastline of Japan, respectively. The offshore component of JARPNII has been conducted mainly from May to September. The coastal component off Sanriku and Kushiro has been conducted mainly in April and September, respectively.

The northern part of the survey area is under the influence of the Oyashio (a subarctic western boundary current with cold, low-salinity water) whereas the southern part is under the influence of the Kuroshio and its extension (the subtropical western boundary current with warm, high-salinity water). The area between the Oyashio and the Kuroshio is called the Kuroshio-Oyashio or subarctic-subtropical transition (interferential) zone (Fig. 1).

The Kuroshio-Oyashio ecosystem is habitats for commercially important species such as Japanese sardine (*Sardinops melanostictus*), Japanese anchovy (*Engraulis japonicus*), Pacific saury (*Cololabis saira*), chub mackerel (S*comber japonicus*) and Japanese common squid (*Todarodes pacificus*) and their population dynamics are influenced by both environmental conditions and fisheries (Yatsu *et al.*, 2013). It is recognized that both climatic and biological regime shifts occurred in the North Pacific Ocean. Commercial catch histories of pelagic fishes have shown drastic fluctuation and quasi-decadal species alterations so-called species replacement in the western North Pacific since the 1950's (Yatsu *et al.* 2001). Species replacement is a form of a biological regime shift. Although there are many definition of regime shift, the study group of fisheries and ecosystem responses to recent regime shift under PICES defined regime shift as "a relative rapid change from one decadal-scale period of a persistent state to another decadal-scale period of persistent state" (King, 2005).Based on climate indices such as the Pacific Decadal Oscillation (PDO) index, various scientific literatures reported that regime shifts were occurred in North Pacific around 1925, 1947, 1977 and 1998 in recent decades (King, 2005; Overland *et al.*, 2008). Responses of pelagic biological organisms to climatic regime shifts were reported including copepods (Tadokoro *et al.*, 2005), Japanese anchovy, Japanese sardine, Pacific saury and mackerel (Takasuka *et al.*, 2008; Tian *et al.*, 2004; Yatsu *et al.*, 2008). It is expected that fluctuation of oceanographic conditions and prey abundance affect spatial distribution and feeding habits of whales.

In this paper, it is investigated that whether oceanographic conditions in the JARPNII survey area were changed from 2000 to 2013 by using FRA-ROMS data. FRA-ROMS is an ocean forecast system developed by Fisheries Research Agency (FRA) based on Regional Ocean Modeling System (ROMS). Trends of annual mean of PDO index and North Pacific Index (NPI) from 1900 and 2015 are also used to investigate whether decadal scale climatic change is occurred in the period. The Niño 3 SST anomaly index (1949-2015) is also used as an indicator of El Niño-Southern Oscillation (ENSO) events.

## MATERIALS AND METHODS

Monthly mean water temperature at 100 and 200 m deep in the entire JARPNII survey area from April to September were prepared using data extracted from FRA-ROMS. Four water types were classified based on following criteria:

Oyashio water: Area where water temperature at 100 m deep is lower than 5°C

Cold water: Area where water temperature at 100 m deep is higher than 5°C and lower than 10°C

Warm water: Area where water temperature at 100 m deep is higher than 10°C and water temperature at 200 m deep is lower than 14°C

Kuroshio water: Area where water temperature at 200 m deep is higher than 14°C

The criteria is conventionally used by FRA for the purpose of oceanographic and fisheries forecast. Area ($km^2$) by water type in each month from 2000 to 2013 were calculated by using the data. Trends in area by water types were investigated by using ordinal linear regressions.

Annual mean PDO index from 1900 to 2015 was calculated using monthly data available from "http://research.jisao.washington.edu/pdo/" [accessed on 6 October 2015]. The PDO index is the leading principal components (PC) from an un-rotated empirical orthogonal function (EOF) analysis of monthly "residual" North Pacific sea surface temperature (SST) anomalies, poleward of 20°N (Mantua and Hare, 2002). Causes of PDO are yet to be determined, but it is assumed that it is related to other climate events such as changes in Aleutian Low Pressure (ALP) and ENSO events. It has been described that decadal change in PDO is related to biological regime shift in the North Pacific as mentioned above.

NPI anomalies in winter in the same period was provided by the Climate Analysis Section, NCAR, Boulder, USA,(Trenberth and Hurrell, 1994) [accessed on 15 October 2015]. The NPI is the area-weighted sea level pressure in the North Pacific bounded by 30°N, 65°N, 160°E and 140°W. NPI anomalies in winter is linked to the ALP. Positive NPI is related to weak ALP while the negative is related to strong ALP. Water temperature in Oyashio is low in the negative phase of NPI while it is high in the positive phase.

The Niño 3 SST index available from Japan Meteorological Agency (http://www.data.jma.go.jp) was used in this paper [accessed on 19 November 2015]. The area bounded by 5°N, 5°S, 150°W and 90°W is termed as "Niño 3" and the SST anomalies in the area is used as a indictor of ENSO events. It is considered as El Niño when the index is positive phase while it is considered as La Niña if the index is negative.

## RESULTS AND DISCUSSION

Maps of water types from April to September by each year (2000-2013) are shown in Figs. 2-15. Trends of area ($km^2$) by water types in each month from 2000 to 2013 are shown in Fig. 16. No statistical significant trend at 5% level was detected except the cold water in September. The results indicated that overall oceanographic conditions in the JARPNII survey area from 2000 to 2013 were relatively stable, although year to year variations and spatial heterogeneity of distribution of water types were observed.

Negative values of annual mean PDO index were dominant in the period from 2000 to 2013 (Fig. 17). It can be considered that JARPNII from 2000 to 2013 was conducted in the negative phase of PDO index, although the index recorded in the future is required to make formal conclusion. Sea surface temperature in the eastern Pacific is high in the positive phase while that in the western Pacific is low (Fig. 18). Vice versa is true for the negative phase. It can be considered that JARPNII from 2000 to 2013 was conducted in warm water temperate in the context of long term oceanographic conditions. Positive values of NPI were dominant from 2000 to 2013 and implied warm water temperate in the JARPNII area (Fig. 19). Generally, NPI showed opposite phases of PDO index. However, there were some discrepancies between these two indices. The discrepancies might be caused by ENSO events (Fig. 20). It seems that ALP is prone to ENSO events in comparison with PDO index. In contrast, PDO index could capture longer term climate change in the North Pacific though relationship among these indices is yet to be determined.

Overall, the results of this study implied that JARPNII from 2000 to 2013 were conducted relatively stable oceanographic conditions. The future survey conducted in the different regime will enhance our understanding how biological organisms including whales response to regime shift in the western North Pacific.

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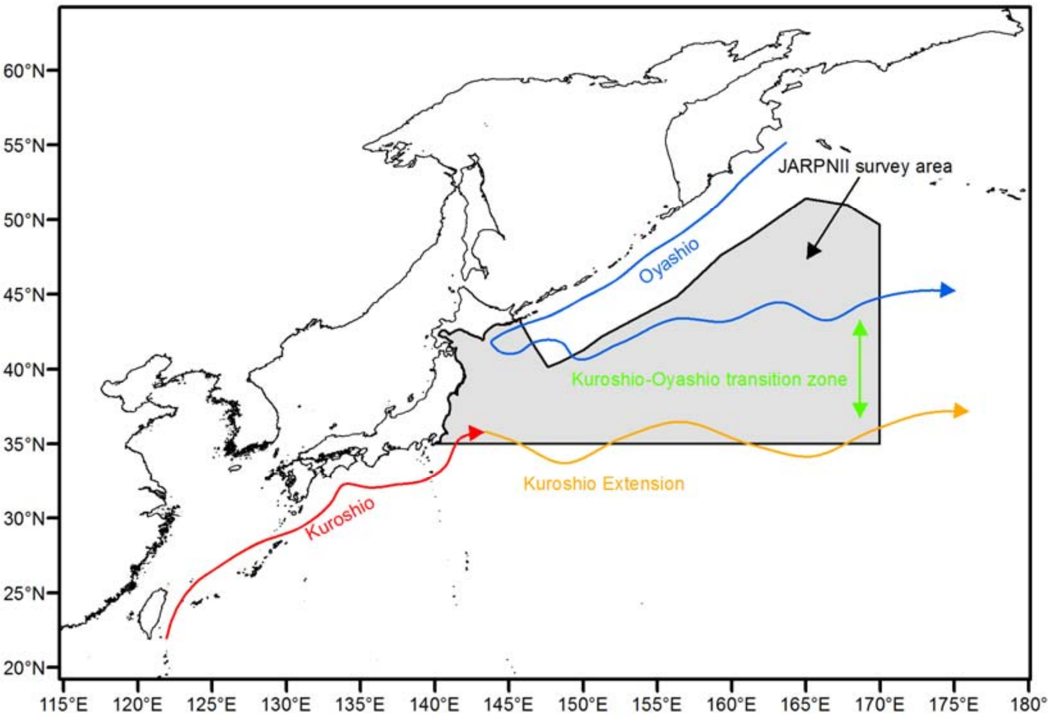



Fig. 1. Schematic map of oceanographic conditions around JARPNII survey area.

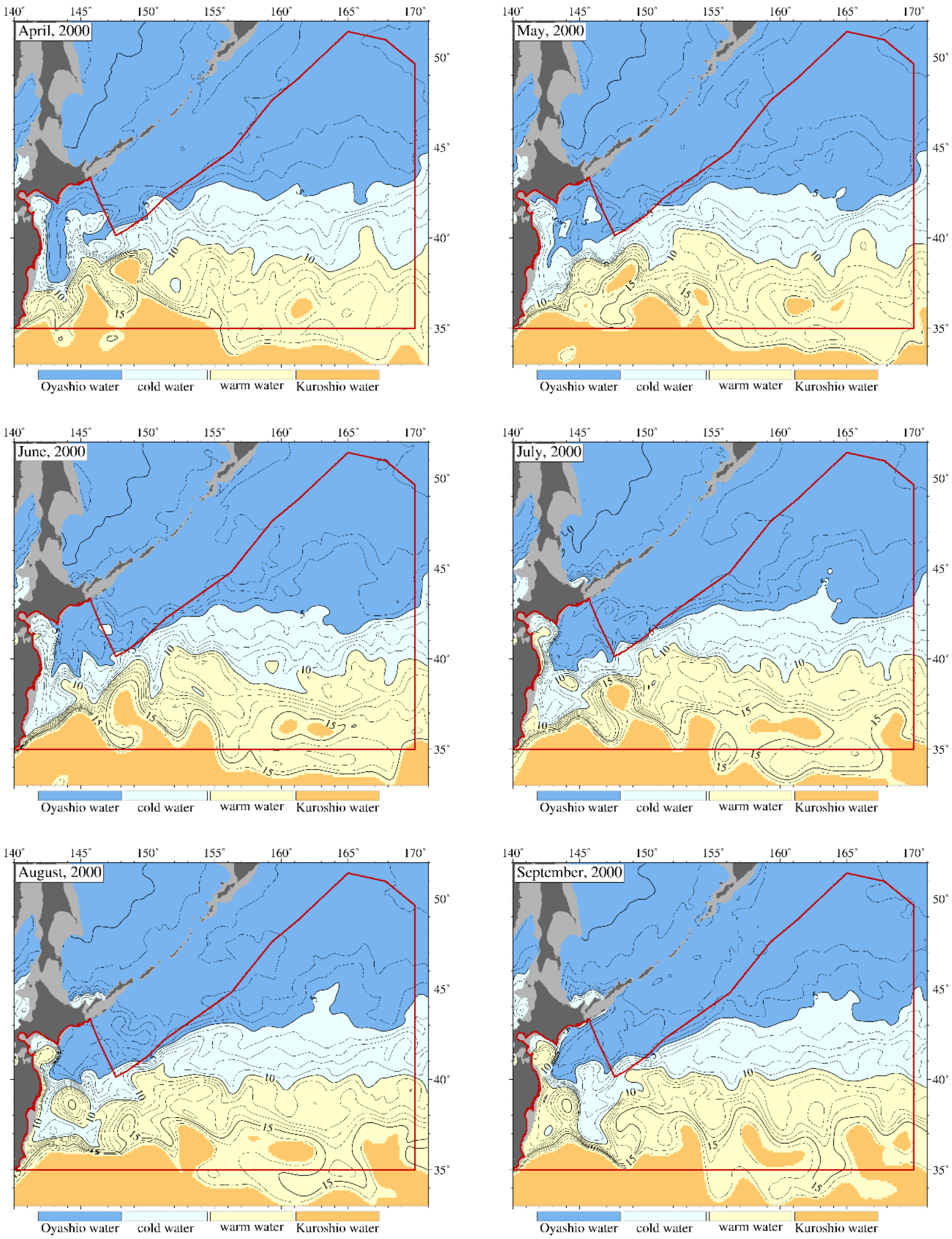



Fig. 2. Water temperature at 100 m deep from April to September in 2000. Four water types (Oyashio, cold, warm and Kuroshio) are shown in the maps. Red lines represents the survey area of JARPNII.

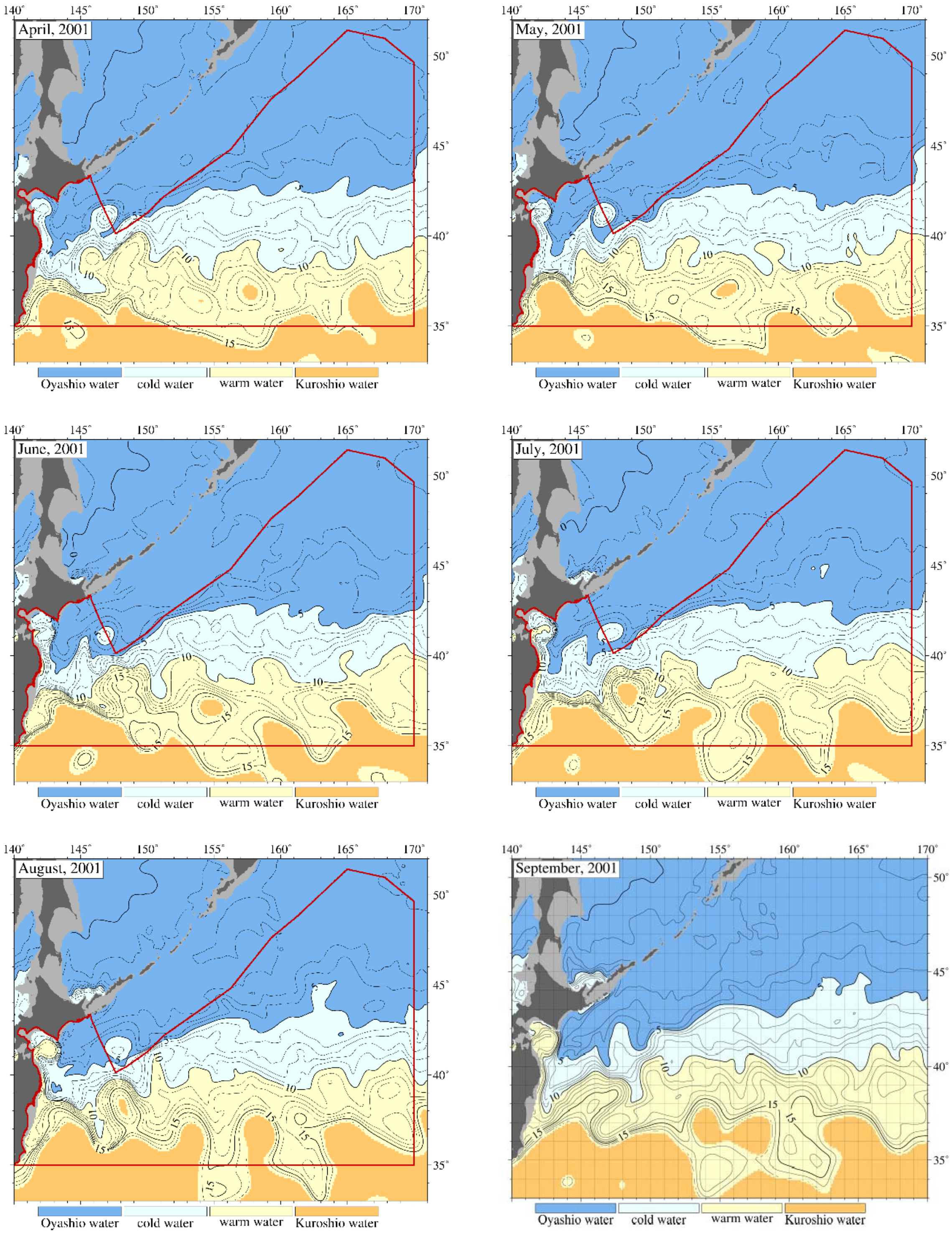



Fig. 3. Water temperature at 100 m deep from April to September in 2001. Four water types (Oyashio, cold, warm and Kuroshio) are shown in the maps. Red lines represents the survey area of JARPNII.

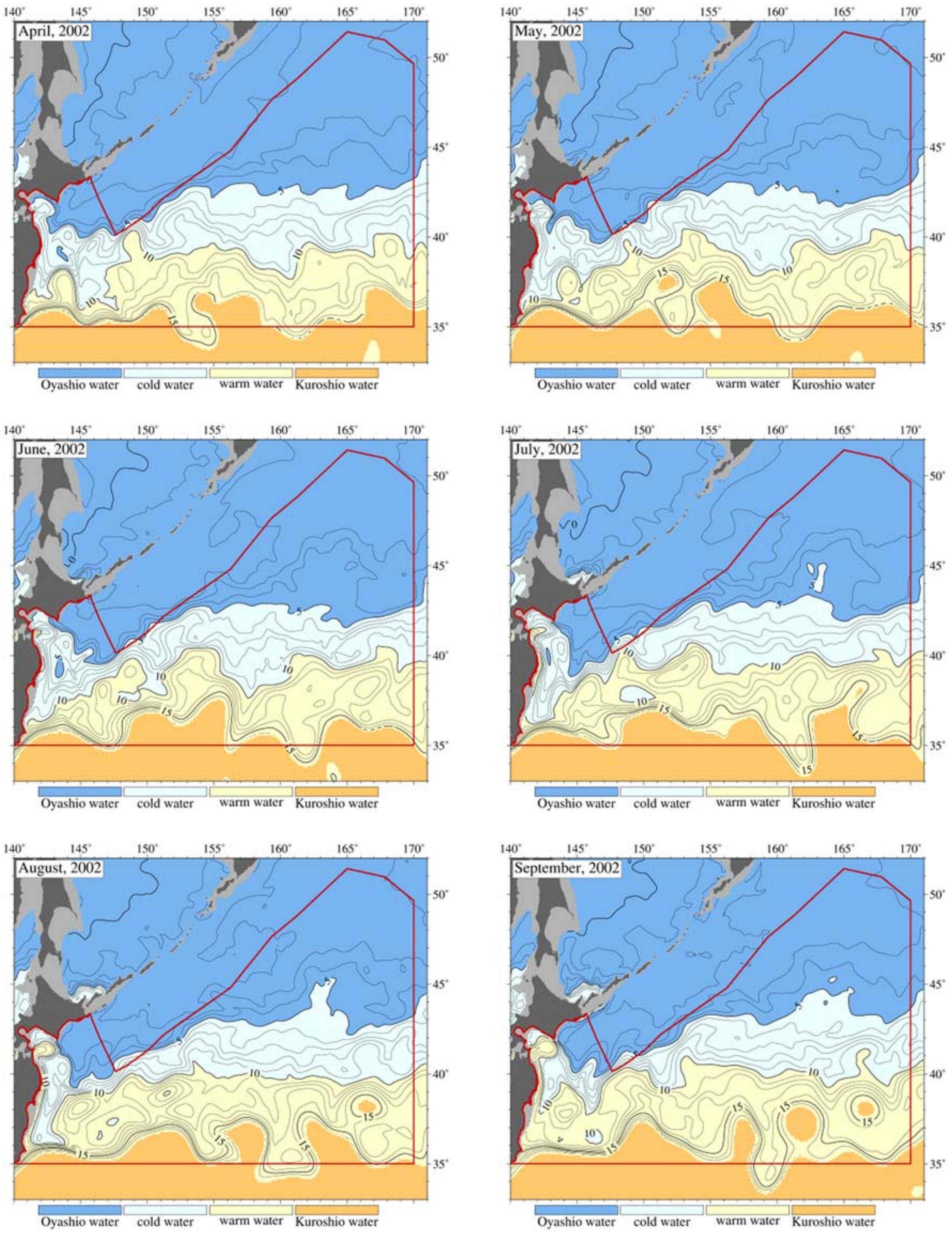



Fig. 4. Water temperature at 100 m deep from April to September in 2002. Four water types (Oyashio, cold, warm and Kuroshio) are shown in the maps. Red lines represents the survey area of JARPNII.

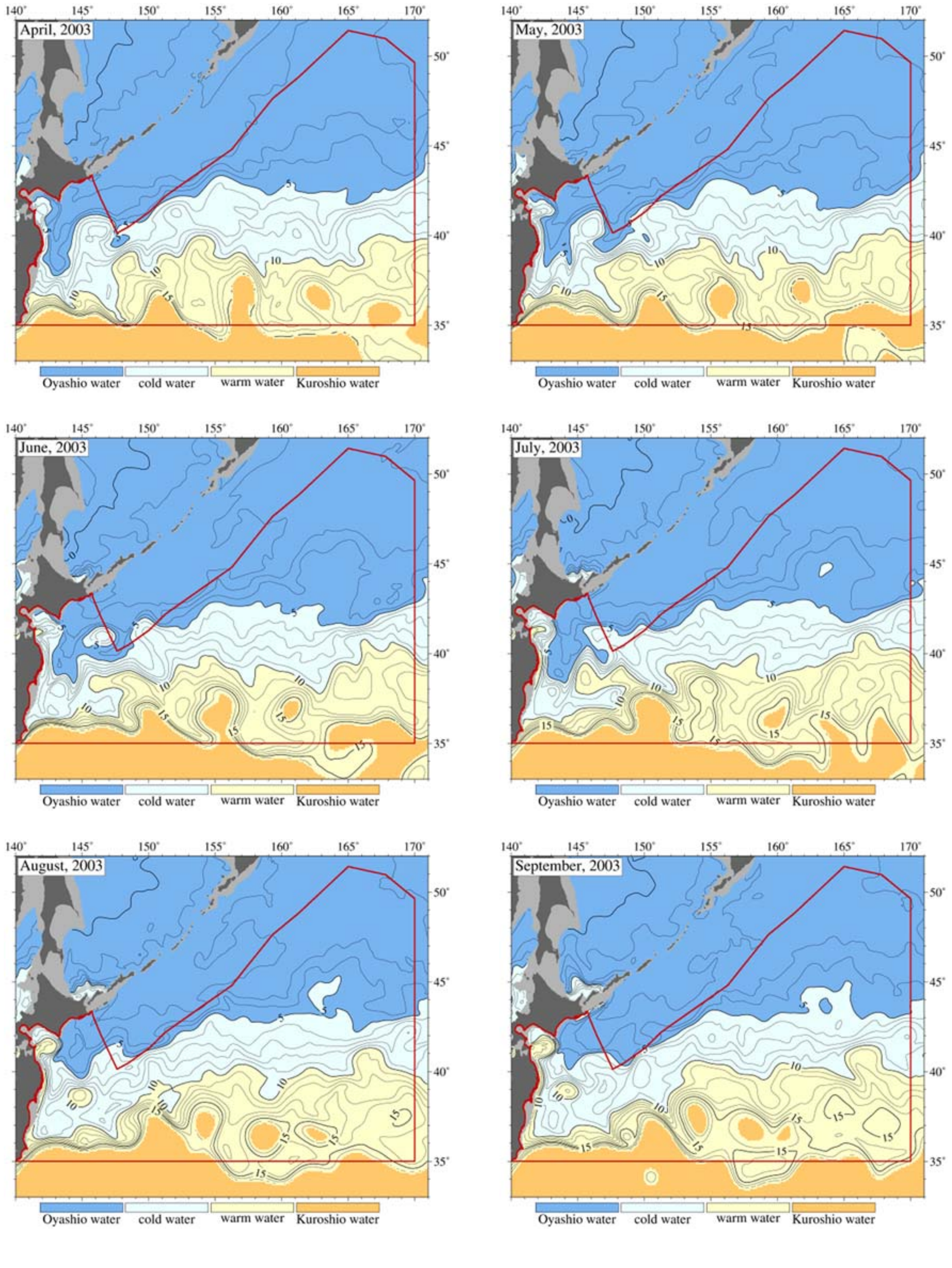



Fig. 5. Water temperature at 100 m deep from April to September in 2003. Four water types (Oyashio, cold, warm and Kuroshio) are shown in the maps. Red lines represents the survey area of JARPNII.

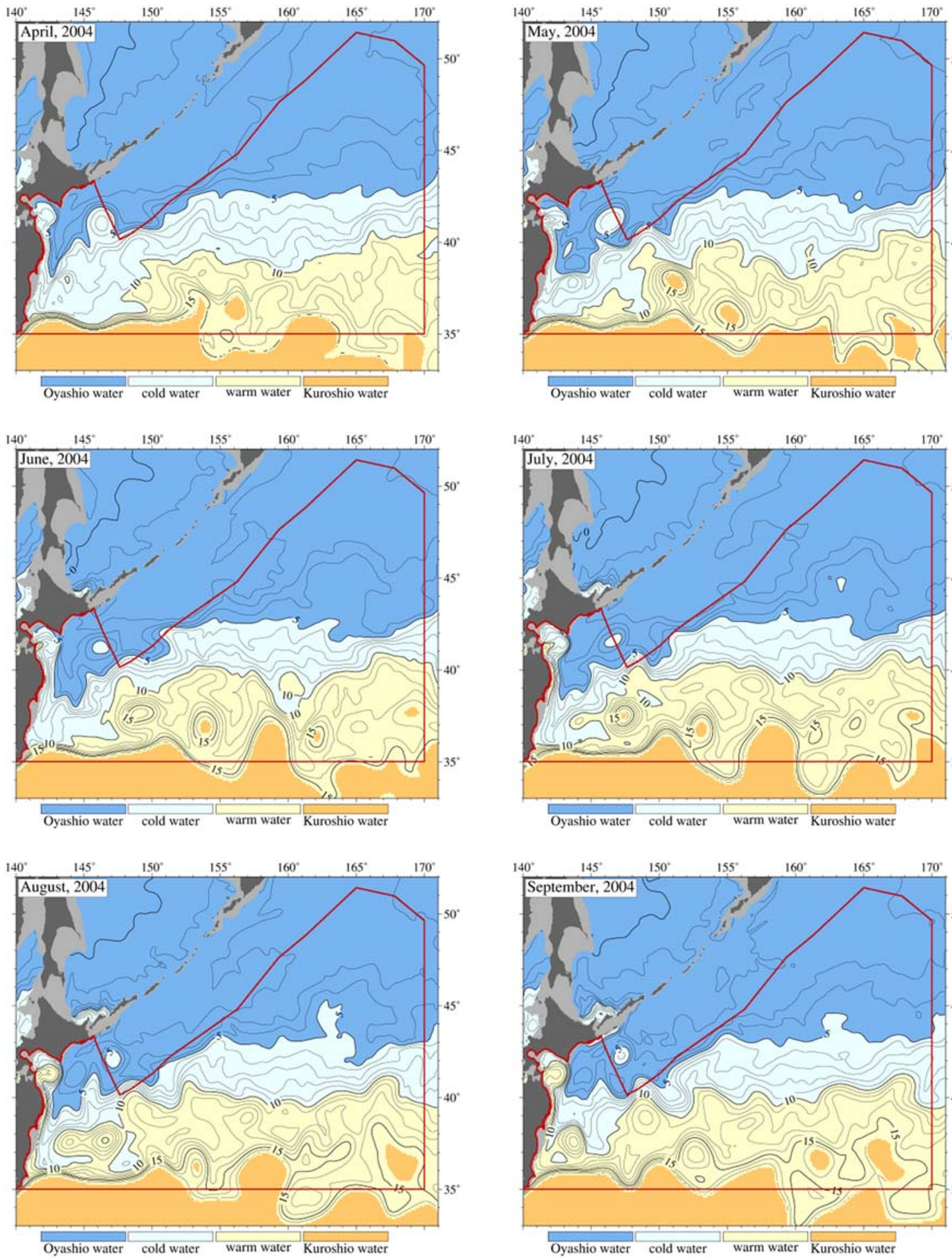



Fig. 6. Water temperature at 100 m deep from April to September in 2004. Four water types (Oyashio, cold, warm and Kuroshio) are shown in the maps. Red lines represents the survey area of JARPNII.

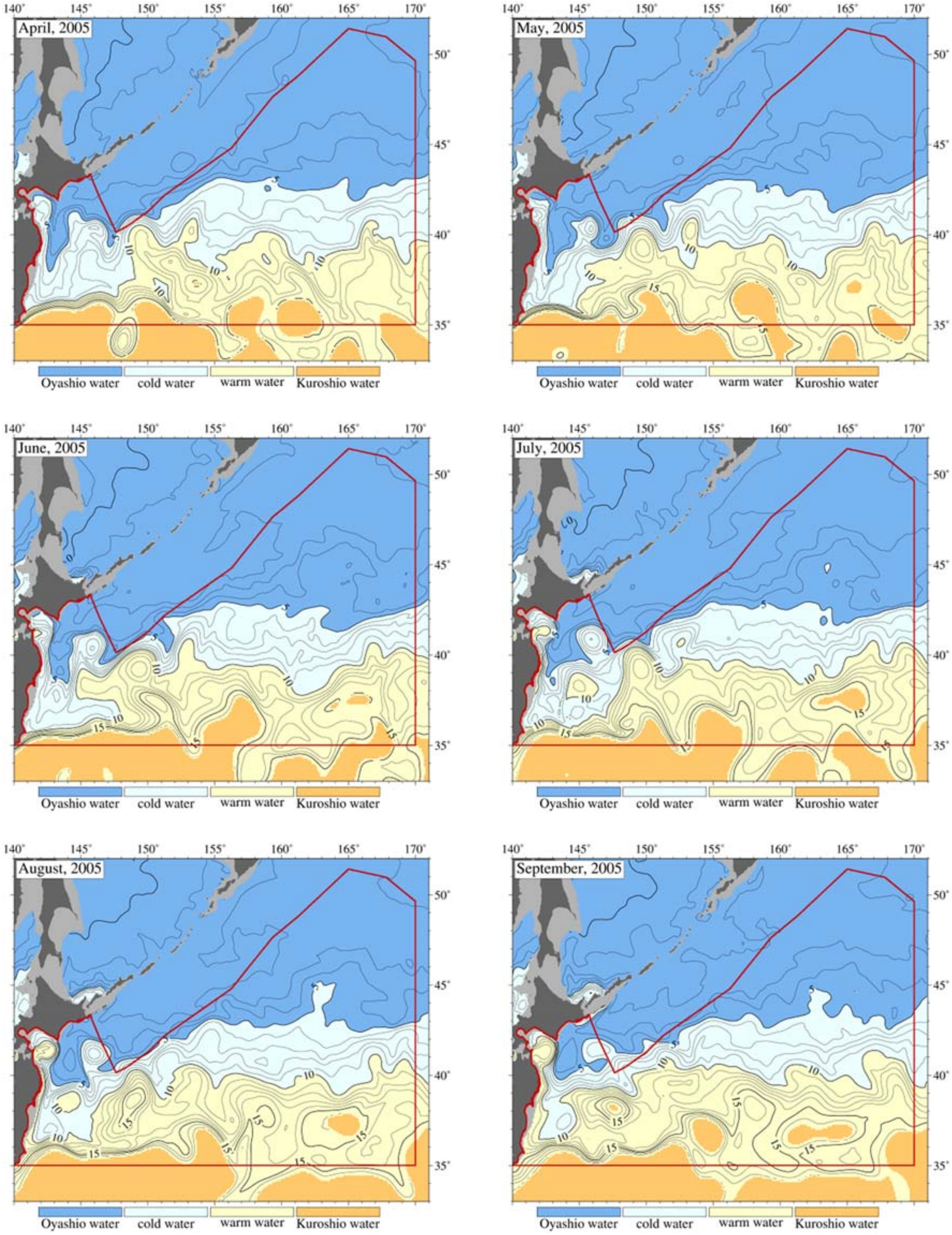



Fig. 7. Water temperature at 100 m deep from April to September in 2005. Four water types (Oyashio, cold, warm and Kuroshio) are shown in the maps. Red lines represents the survey area of JARPNII.

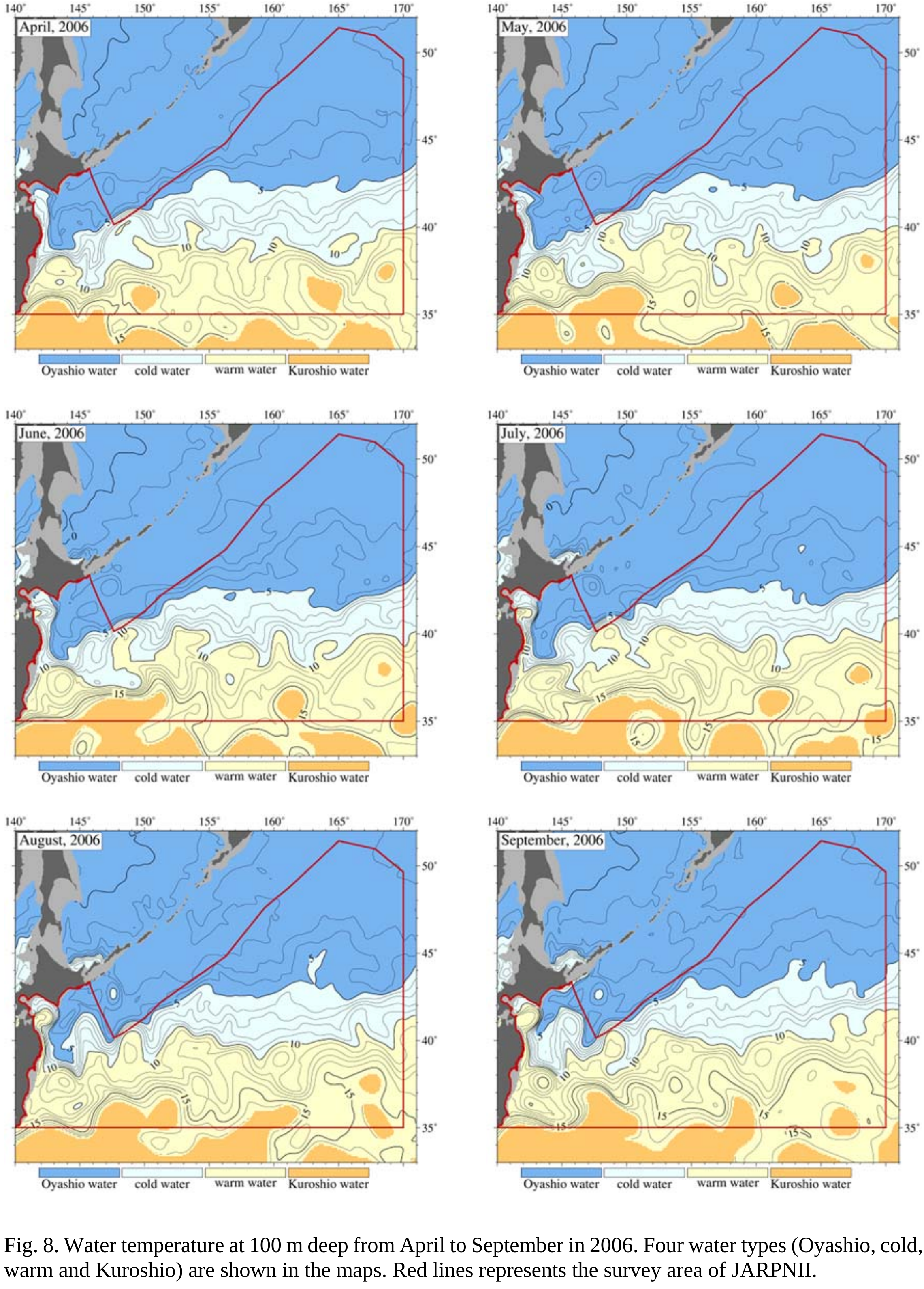



Fig. 8. Water temperature at 100 m deep from April to September in 2006. Four water types (Oyashio, cold, warm and Kuroshio) are shown in the maps. Red lines represents the survey area of JARPNII.

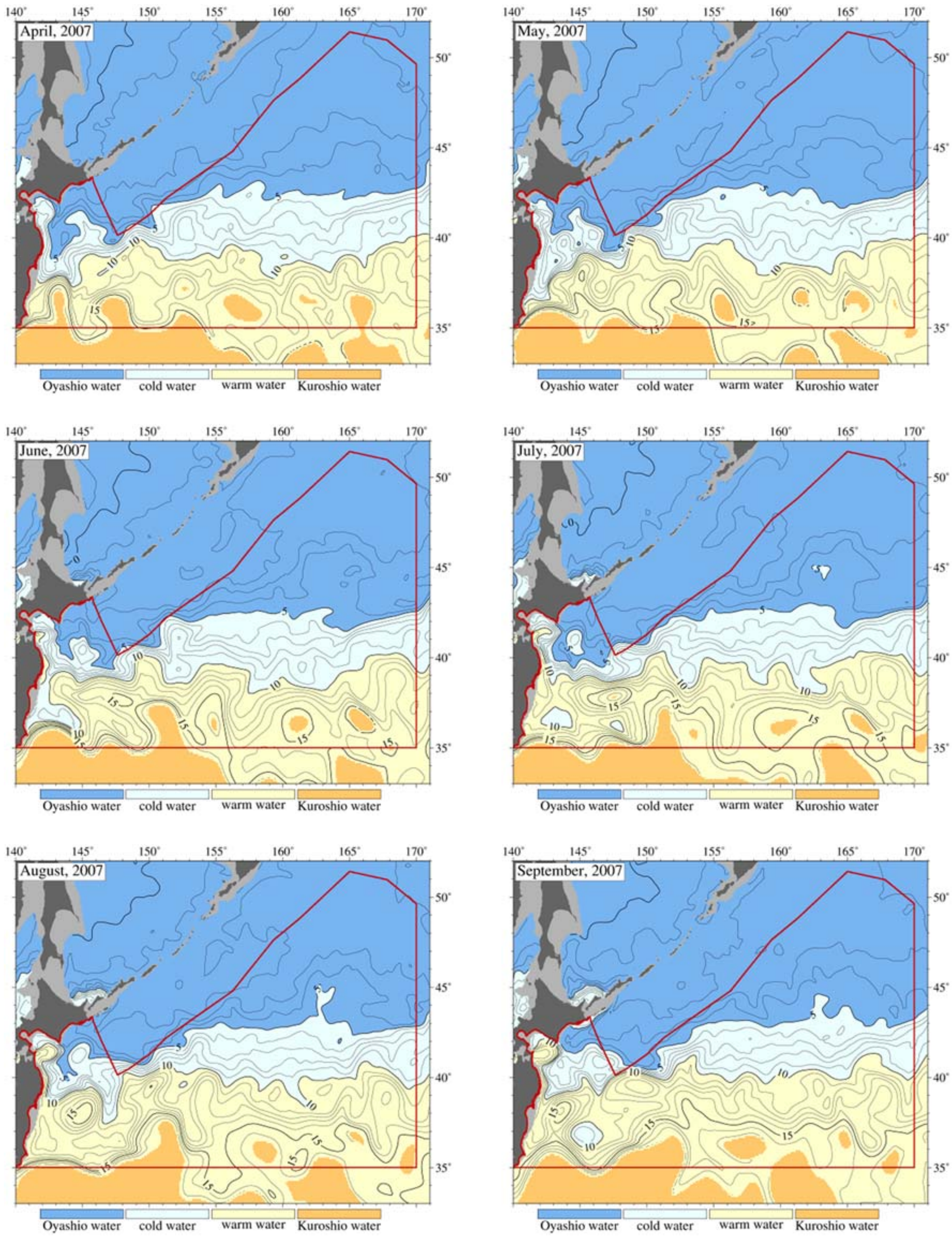



Fig. 9. Water temperature at 100 m deep from April to September in 2007. Four water types (Oyashio, cold, warm and Kuroshio) are shown in the maps. Red lines represents the survey area of JARPNII.

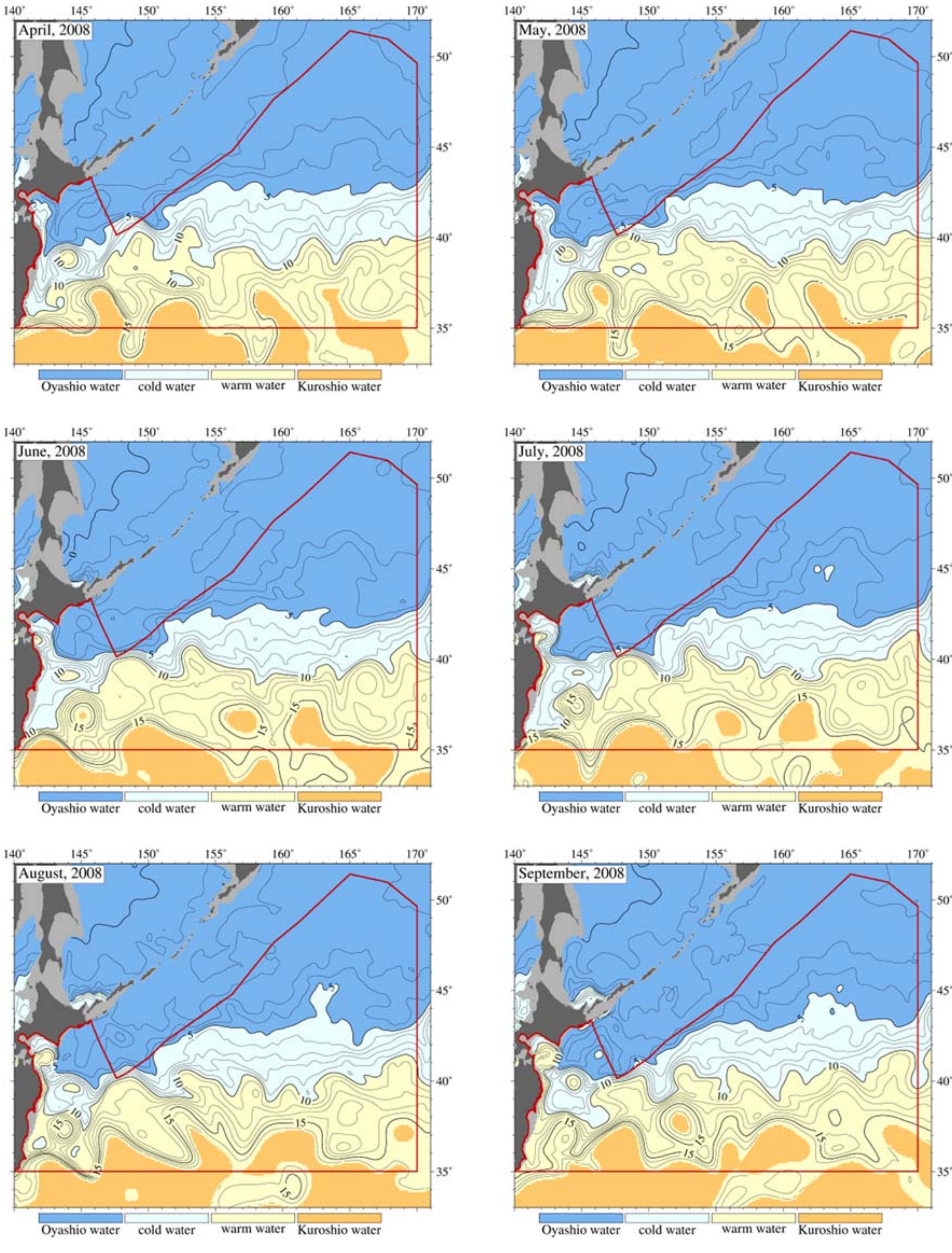



Fig. 10. Water temperature at 100 m deep from April to September in 2008. Four water types (Oyashio, cold, warm and Kuroshio) are shown in the maps. Red lines represents the survey area of JARPNII.

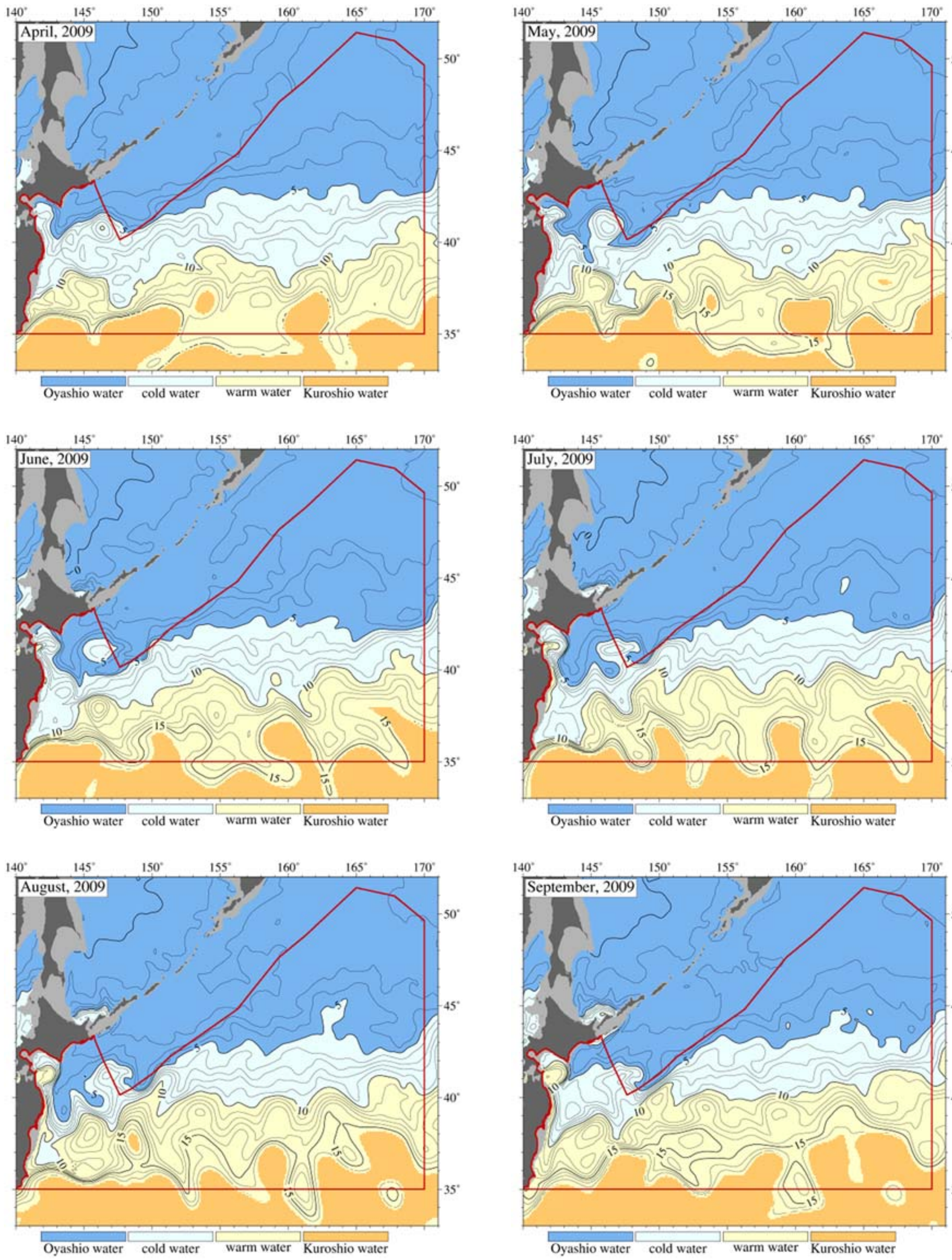



Fig. 11. Water temperature at 100 m deep from April to September in 2009. Four water types (Oyashio, cold, warm and Kuroshio) are shown in the maps. Red lines represents the survey area of JARPNII.

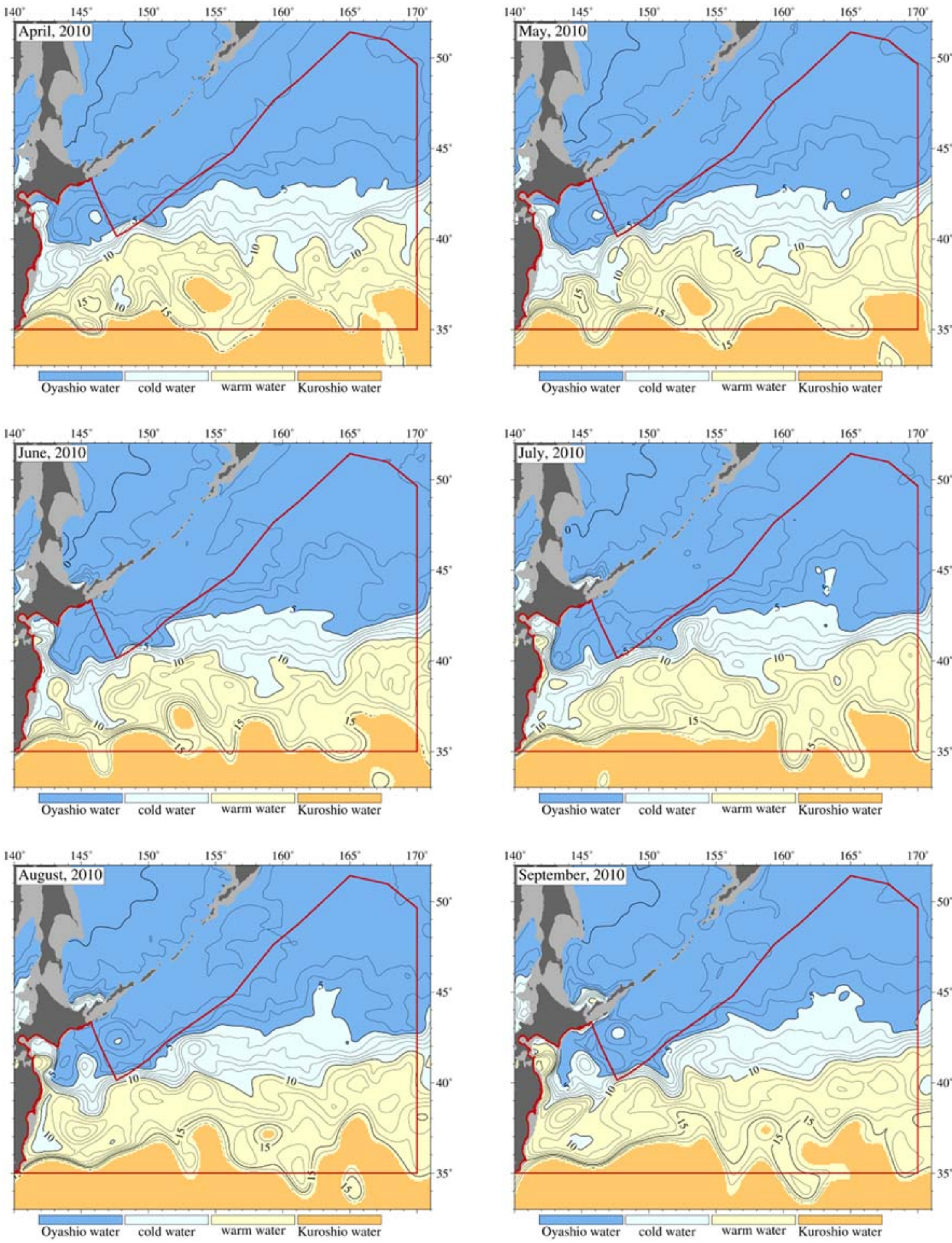



Fig. 12. Water temperature at 100 m deep from April to September in 2010. Four water types (Oyashio, cold, warm and Kuroshio) are shown in the maps. Red lines represents the survey area of JARPNII.

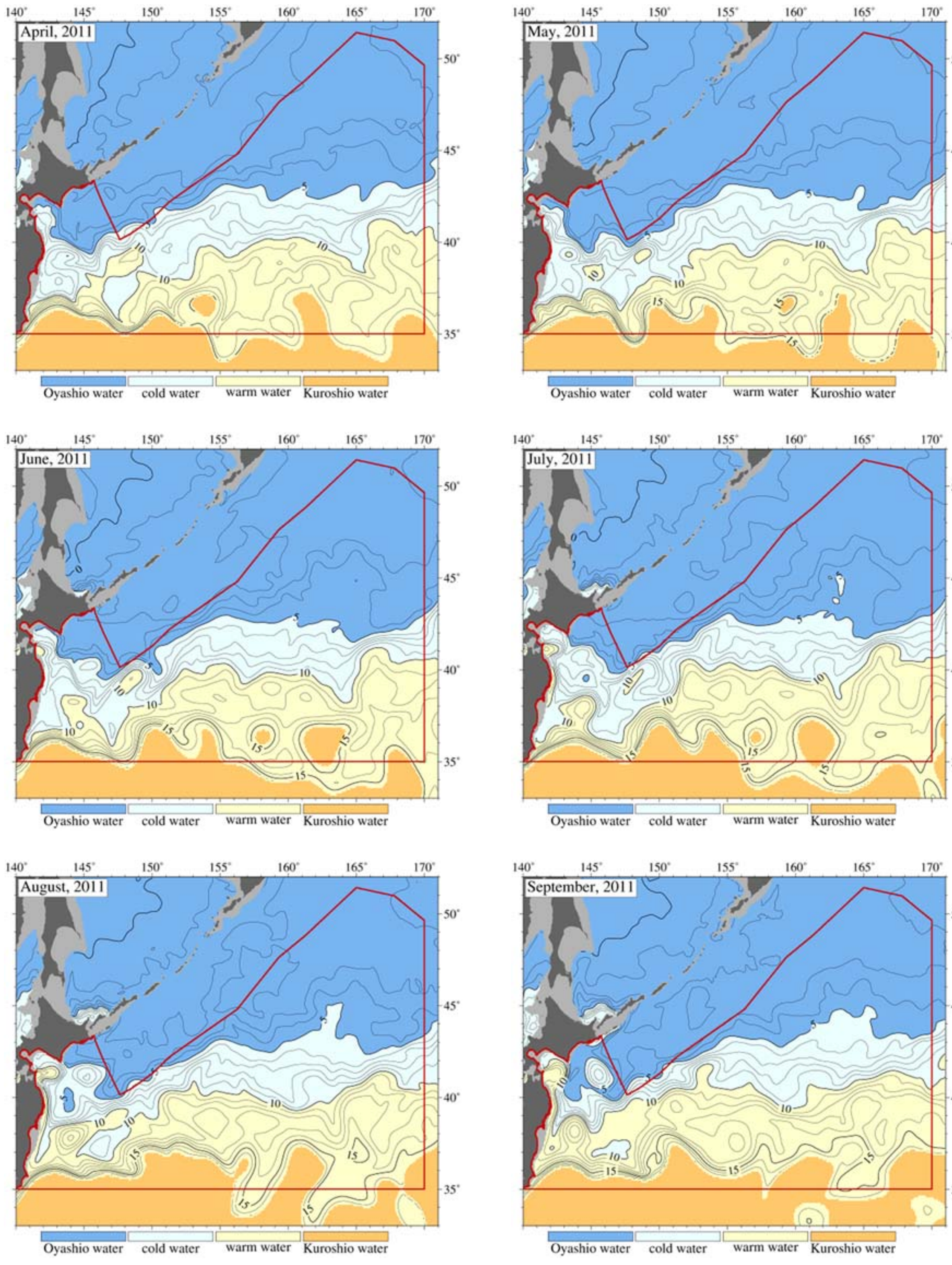



Fig. 13. Water temperature at 100 m deep from April to September in 2011. Four water types (Oyashio, cold, warm and Kuroshio) are shown in the maps. Red lines represents the survey area of JARPNII.

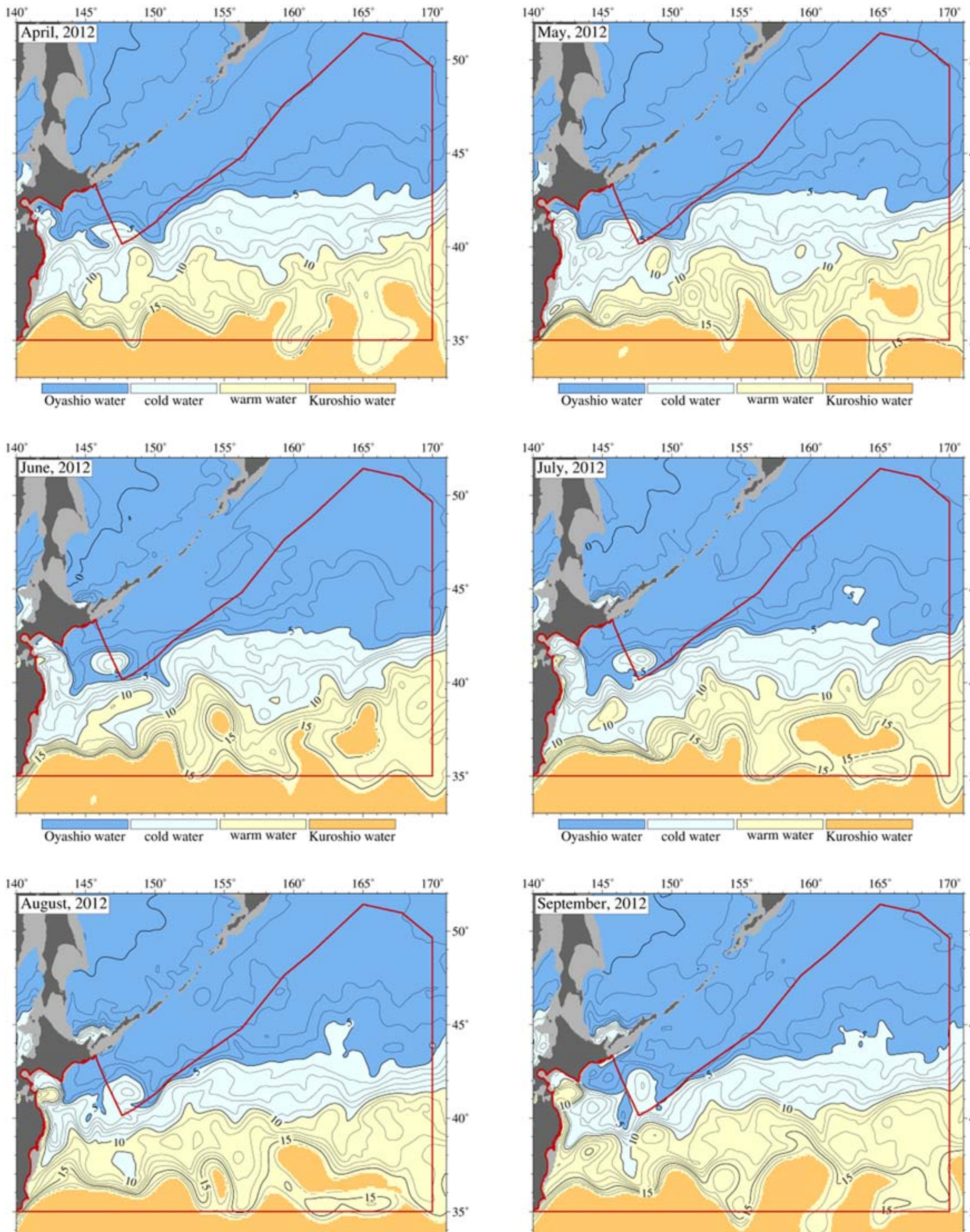



Fig. 14. Water temperature at 100 m deep from April to September in 2012. Four water types (Oyashio, cold, warm and Kuroshio) are shown in the maps. Red lines represents the survey area of JARPNII.

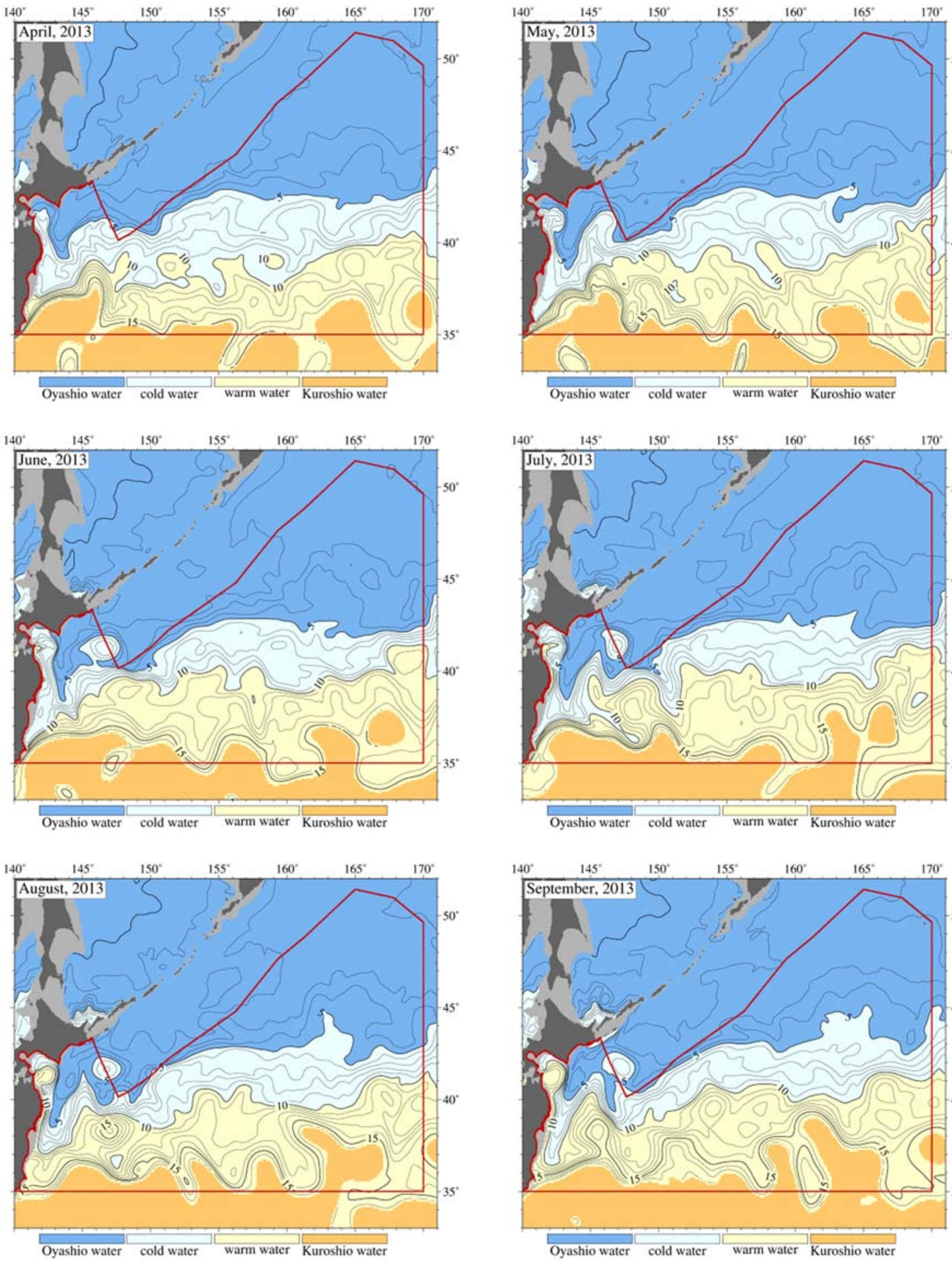
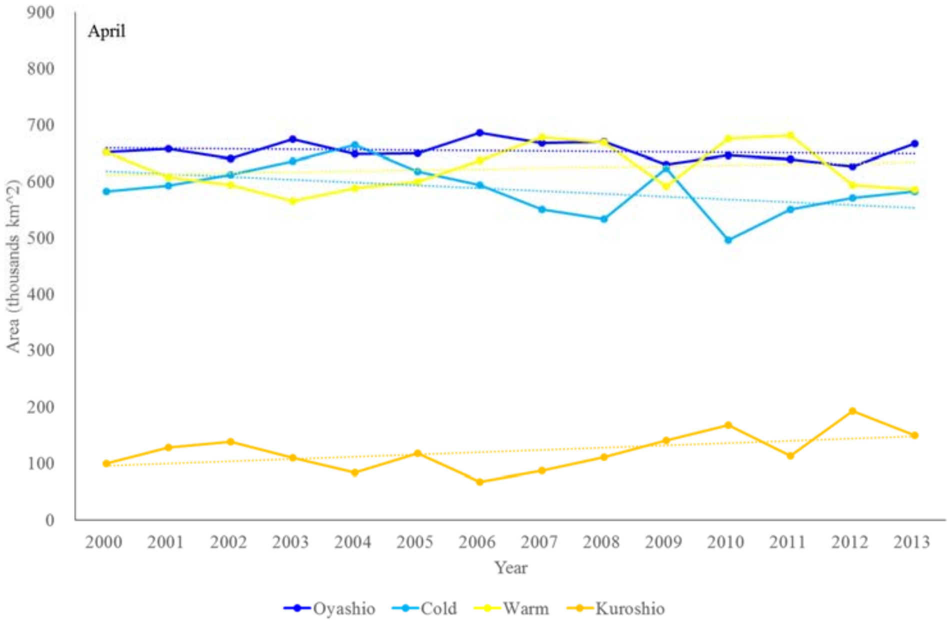



Fig. 15. Water temperature at 100 m deep from April to September in 2013. Four water types (Oyashio, cold, warm and Kuroshio) are shown in the maps. Red lines represents the survey area of JARPNII.



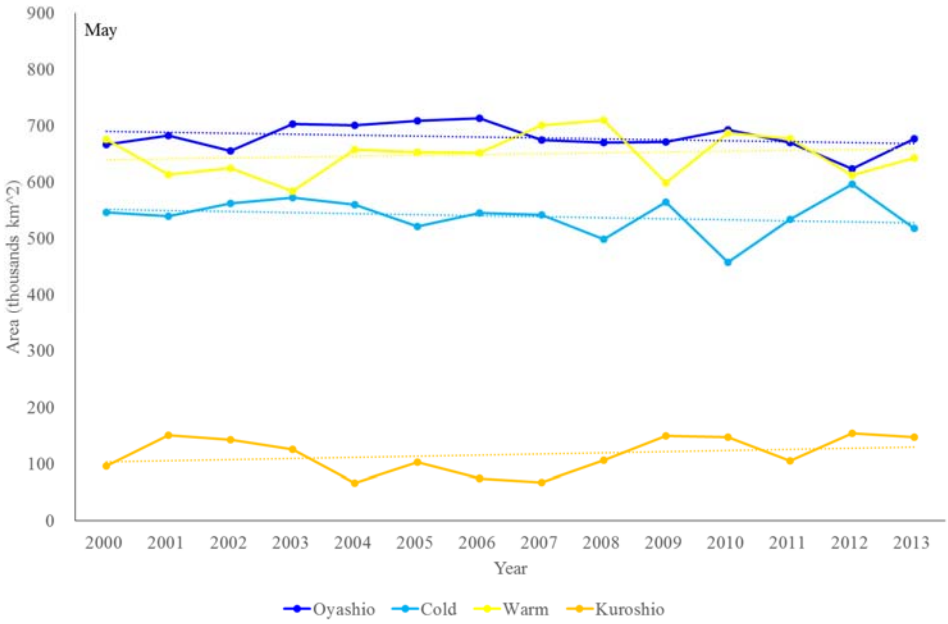
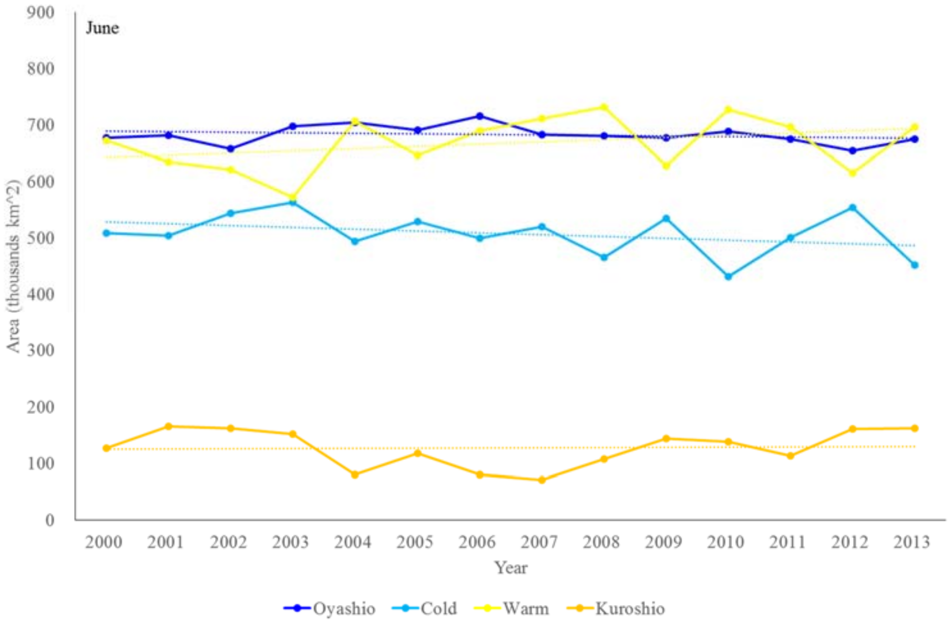
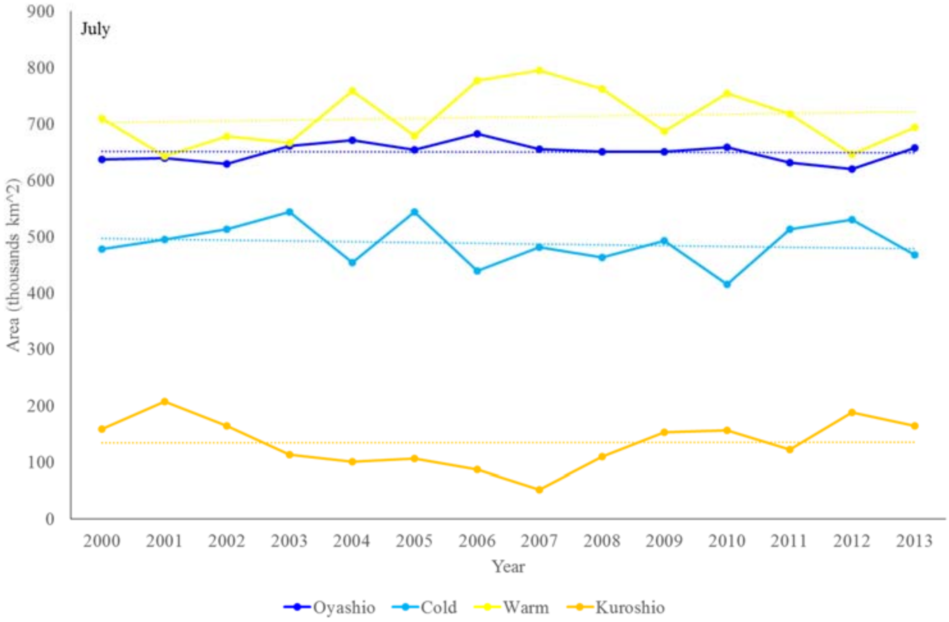




Fig. 16. Trends in area ($km^2$) by water types (Oyashio, cold, warm and Kuroshio) within the survey area from April to September in the period of JARPNII (2000-2013).

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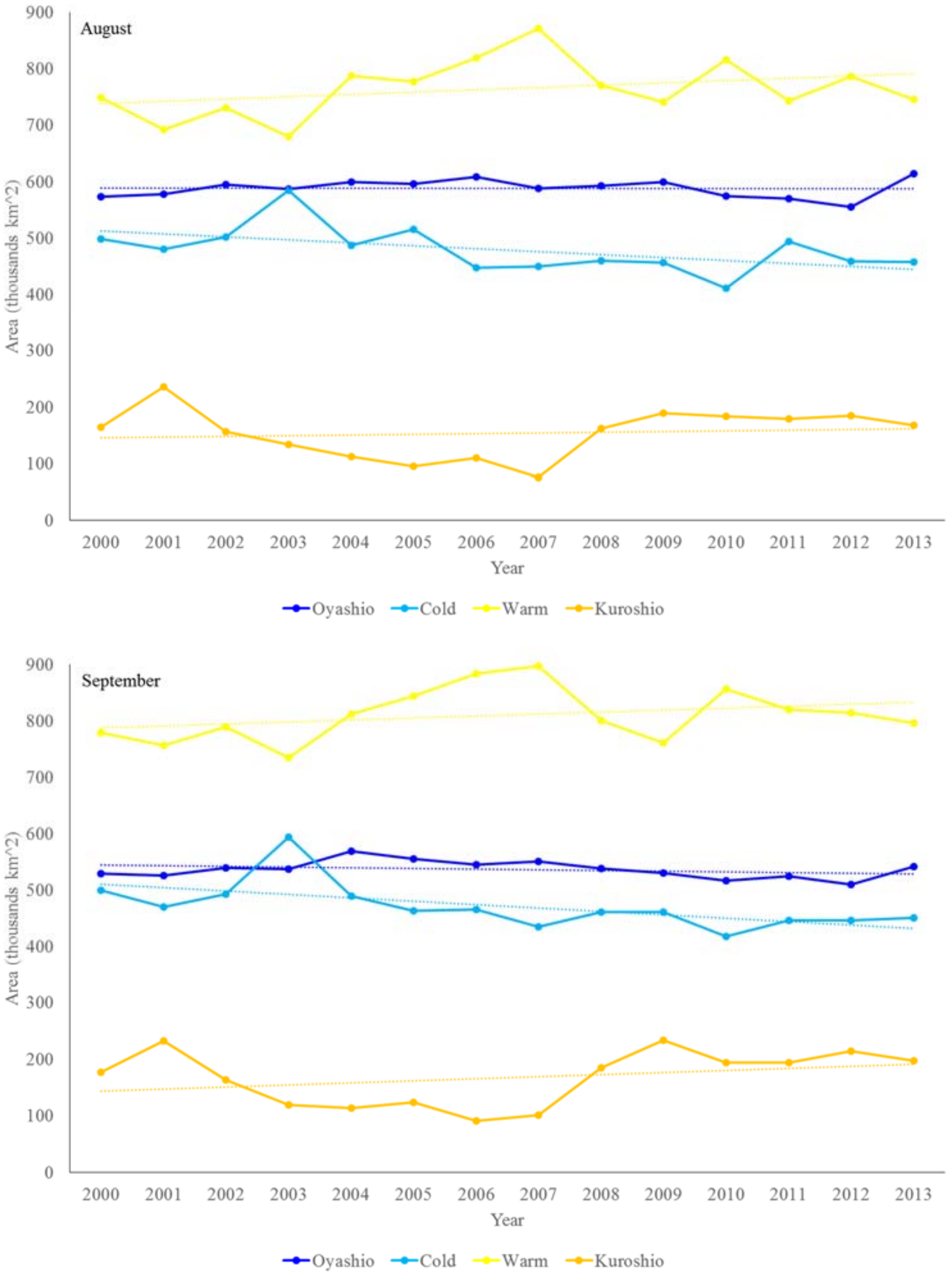


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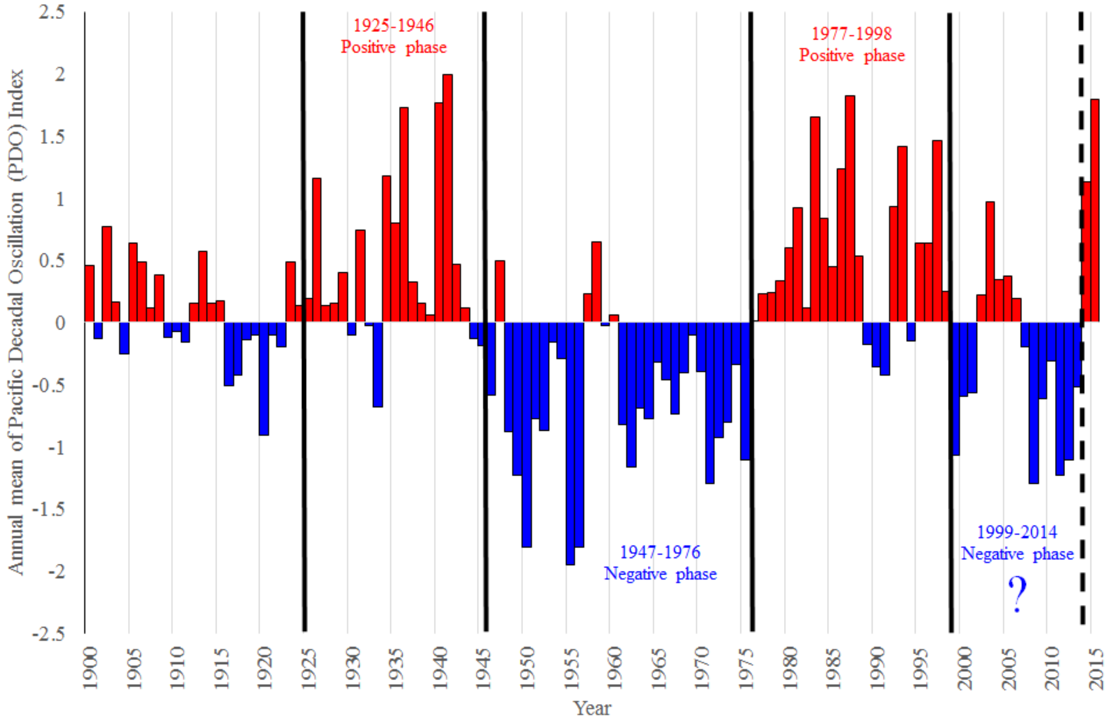


Fig. 17. Annual mean of Pacific Decadal Oscillation (PDO) index from 1900 to 2015. Monthly PDO data available from "http://research.jisao.washington.edu/pdo/" (accessed on 6 October 2015) are used to calculate annual mean. Climate regime shift indicated in several published papers are also shown in the figure (see main text for the details). Note: Sea surface temperature in the eastern Pacific is high in the positive phase while that in the western Pacific is low. Vice versa is true for the negative phase.

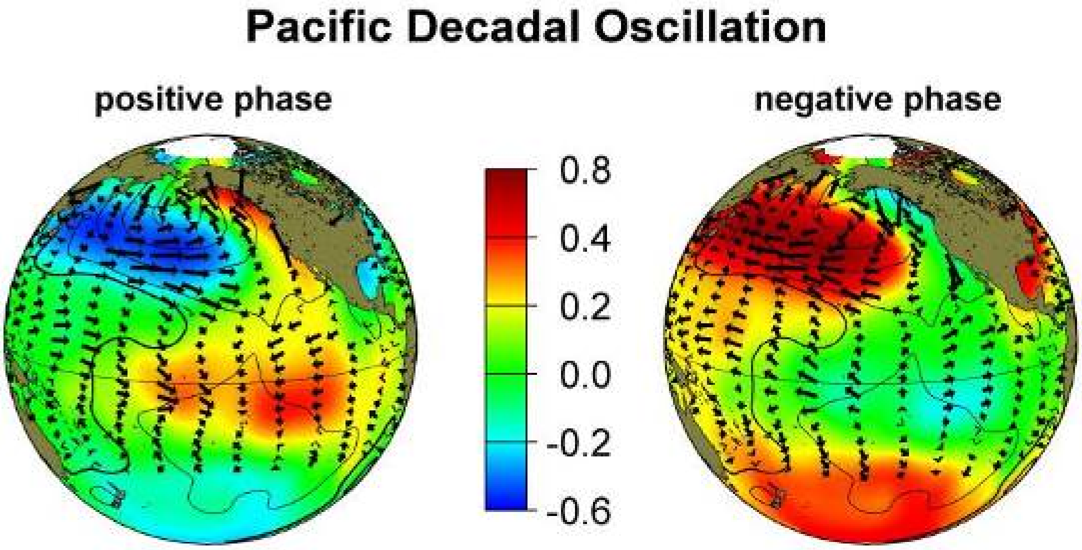


Fig 18. Schematic maps showing sea surface temperature (SST), sea level pressure (SLP) and surface wind stress anomaly in the positive and negative phases of Pacific Decadal Oscillation (PDO) Index. The maps are available from http://research.jisao.washington.edu/pdo/graphics.html. Sea surface temperature in the eastern Pacific is high in the positive phase while that in the western Pacific is low. Vice versa is true for the negative phase.

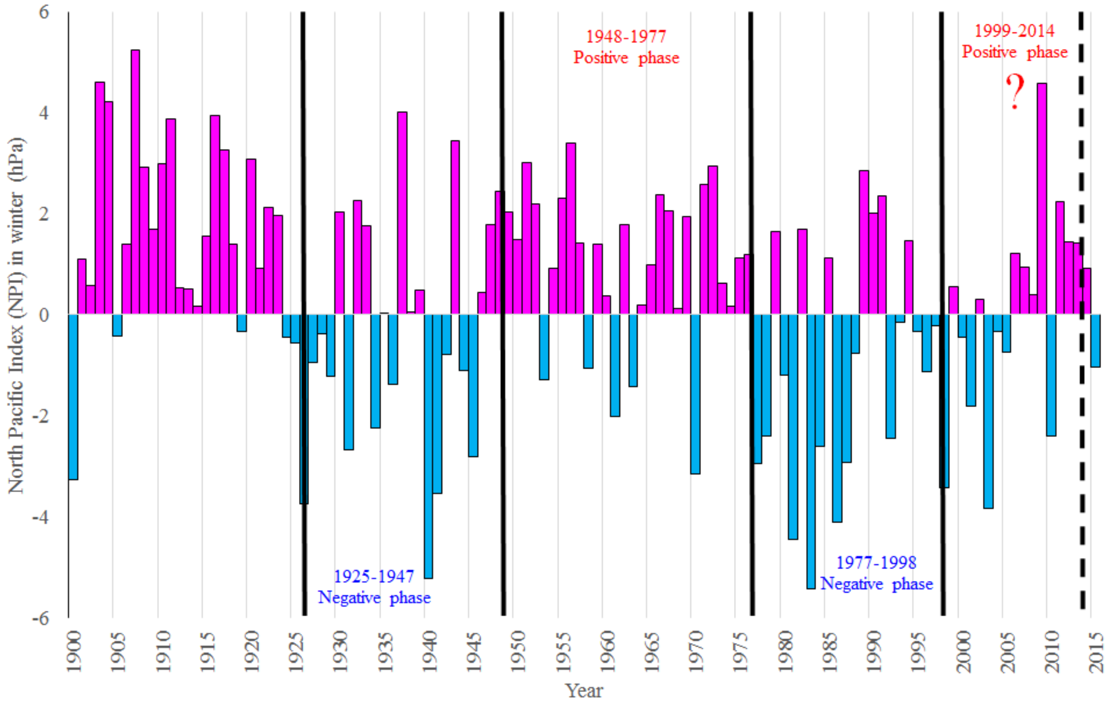


Fig. 19 North Pacific Index (NPI) in winter from 1900 to 2015. The data were provided by the Climate Analysis Section, NCAR, Boulder, USA, (Trenberth and Hurrell, 1994) [accessed on 15 October 2015]. Climate regime shift indicated in several published papers are also shown in the figure (see main text for the details). NPI winter anomalies in winter is linked to the ALP. Positive NPI is related to weak ALP while the negative is related to strong ALP. Temperature in Oyashio is low in the negative phase of NPI while it is high in the positive phase.

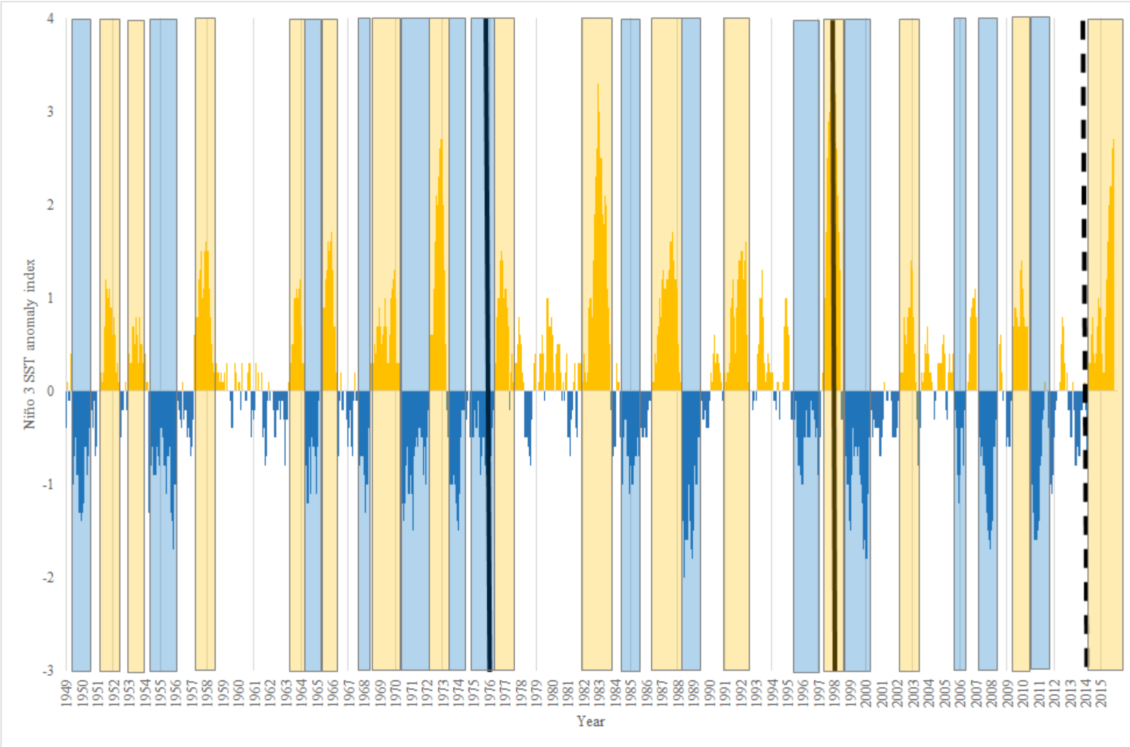


Fig. 20. The Niño 3 SST anomaly index from 1949 to 2015 Data were available from Japan Meteorological Agency (http://www.data.jma.go.jp) [accessed on 19 November 2015]. It is considered as El Niño when the index is positive phase (orange) while it is considered as La Niña (blue). Climate regime shift indicated in several published papers are also shown in the figure as black lines (see main text for the details).