

## Case Study 12

# Application of Multi-Sensor Satellite and Fishery Data, Statistical Models and Marine-GIS to Detect Habitat Preferences of Skipjack Tuna

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## 12.1 Introduction

Advances in satellite remote sensing of the oceans have expanded our knowledge of oceanographic phenomena at spatial and temporal scales previously inconceivable from ship and buoy platforms. Satellite remote sensing data used in oceanographic work is mainly from sea surface temperature (SST), ocean colour and ocean altimetry. Application of geographic information systems (GIS), remotely-sensed imagery and statistical models in fisheries oceanography (Valavanis et al., 2008) are also widening the scope of marine studies in time and space. GIS, widely developed for land-based applications, have grown to accommodate oceanographic work by incorporating functions that handle multiple dimensionality and dynamism of marine data (Wright and Goodchild, 1997). Analyses of remotely-sensed data and fisheries data under a GIS environment have facilitated elucidation of fundamental relationships between marine biota and their oceanic environment (Valavanis et al., 2008). Coupling of GIS applications and geo-statistical models thus provide a platform for integrating diverse forms of data to provide scientifically underpinned information for marine resource management. The objective of this case study is to illustrate how remotely-sensed information can be used to derive habitat indices for pelagic species such as skipjack tuna.

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## 12.2 Background

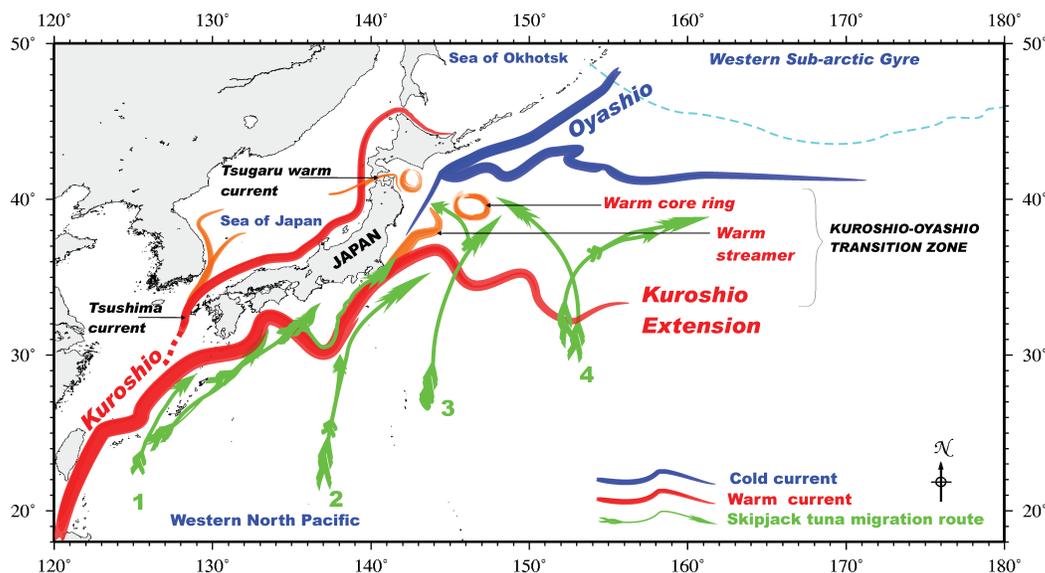
Global tuna catches have increased steadily from a half million tonnes in 1950 to almost 4 million tonnes in 1999 (Miyake et al., 2004). The Pacific Ocean has the highest proportion of catches (65%) compared to about 15 and 20% for the Atlantic and Indian Oceans respectively (Miyake et al., 2004). Skipjack tuna is one of the species whose catches have risen consistently in the past decade (FAO, 2009), and in catch volumes, the species ranks third after anchovies and the Alaskan Pollock. The western Pacific produces substantial skipjack tuna catches. Skipjack tuna utilize the upper pelagic environment for their habitat; hence satellite data provide appropriate observations for their horizontal habitats. Skipjack tuna are known to associate with thermal fronts, warm water streamers and eddies in the western North Pacific (Tameishi and Shinomiya, 1989; Sugimoto and Tameishi, 1992), which are features that can be distinguished from satellite remotely-sensed SST, ocean colour or altimetry data. Studying skipjack tuna's habitat from remotely-sensed environmental data provides a scientific basis for understanding their response to externalities such as climate change and fishing pressure. Habitat models based on remotely-sensed data can facilitate fishery forecasting, effort control or design of dynamic marine protected areas.

Skipjack tuna in the western Pacific migrate as far as 44°N off Japan (Wild and Hampton, 1993; Langley et al., 2005). Migration patterns follow a north-south seasonal cycle where migration to higher latitudes occurs in the fall-summer season (Kawai and Sasaki, 1962; Matsumoto, 1975; Ogura, 2003). Migration is influenced by ocean currents and the fish move along prevailing currents utilizing them as foraging habitats (Uda and Ishino, 1958; Uda, 1973). The western most groups are comprised of one originating from the Philippine islands and a second group from the Marianna-Marshall islands (Figure 12.1). These groups migrate northwards along the Japanese coastal waters. A third group originates east of the Marshall Islands and moves in a northwesterly direction into Japanese offshore waters (Matsumoto, 1975). Part of this group could move farther downstream of the Kuroshio Current to the east of the Midway Island. In late summer and early autumn, the fish begin their southward migration.

## 12.3 Data and Methods

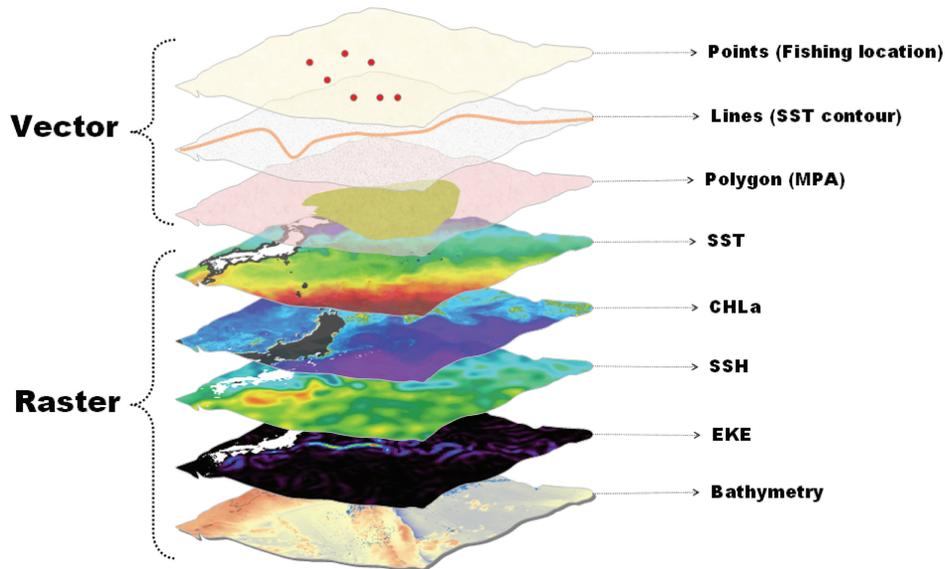
### 12.3.1 Study area

To enable one to appreciate the application of remotely-sensed imagery used in tuna ecology in the western North Pacific, a brief description of the key physical oceanographic features of this ecosystem is given here. The western North Pacific (Figure 12.1) is a productive ecosystem influenced mainly by the Kuroshio Current, Oyashio Current and the Tsugaru Warm Current (Talley et al., 1995). First, we



**Figure 12.1** Northern migration (mainly from spring) pattern of skipjack tuna (green lines) off the south and east coasts of Japan in the western North Pacific. The migration pattern is largely influenced by temperature and ocean currents. Modified from Nihira (1996).

will describe the two main currents in this ecosystem: the Kuroshio and Oyashio currents. The Oyashio Current (Figure 12.1), formed by waters from the Okhotsk Sea and the Subarctic Gyre (Yasuda, 2003), flows southward, transporting low-temperature, low-salinity and nutrient-rich waters to the North Pacific Subtropical Gyre (Sakurai, 2007). The current commonly meanders twice after leaving the coast of Hokkaido, generating the first and second intrusions (Kawai, 1972). The meanders are separated by a warm core ring (WCR) originating from the northward movement of the ring produced by the Kuroshio Current (Yasuda et al., 1992). The southern limit of subpolar waters is often referred to as the Oyashio Front (Talley et al., 1995). The Oyashio ecosystem is an important fishing ground for several subarctic species and subtropical migrants (Saitoh et al., 1986). The Kuroshio Current (Figure 12.1) originates from the subtropical gyre and is distinguished by low density, nutrient poor, warm and high salinity surface waters (Kawai, 1972; Talley et al., 1995). The Kuroshio Extension is an eastward-flowing inertial jet characterized by large-amplitude meanders and energetic pinched-off eddies, with high eddy kinetic energies (Qiu, 2002). Confluence of the two currents results in a mixed region, the Kuroshio-Oyashio Transition Zone (Yasuda, 2003). The behaviour of the Kuroshio Extension, warm streamers and WCRs in the Transition Zone is important to the fishing industry (Saitoh et al., 1986; Sugimoto and Tameishi, 1992). The Tsugaru Warm Current originates from the Tsushima Current and flows with warm and saline water from the Sea of Japan (Talley et al., 1995). The recognition of these dynamic oceanographic features by satellite sensors at varying time scales makes remote



**Figure 12.2** A graphic representation of the core GIS data types, vector (point, line and polygon) and raster (imagery) data.

sensing an invaluable tool in ecological studies.

### 12.3.2 GIS data types

Geographic information system data types are largely classified into vector and raster data types (Figure 12.2). Vector data are data types that represent real world features as points (fishing location or buildings), lines (a contour or road), or polygons (a marine protected area or car park). Raster data represent real world features as grids, which store values that are used to interpret the real world feature (e.g. a SST image or bathymetry). Both data formats are useful in a GIS in different scenarios. It is important to point out the differences so as to make their usage in subsequent sections convenient. A schematic diagram illustrating how the different types of data are integrated in a GIS during analyses is shown in Figure 12.3.

### 12.3.3 Image processing and GIS software

There are several types of image processing and GIS software available that can be used to analyze remotely-sensed oceanographic data. Some are commercial while others can be downloaded freely from the internet. It is not possible to draw an exhaustive list of available software here, but ArcGIS, Erdas Imagine and Idrisi are some of the commercially-available software capable of working with remotely-sensed imagery. On the other hand, the generic mapping tools (GMT), SeaDAS and GRASS are freely available for download from the internet. For this case study, we

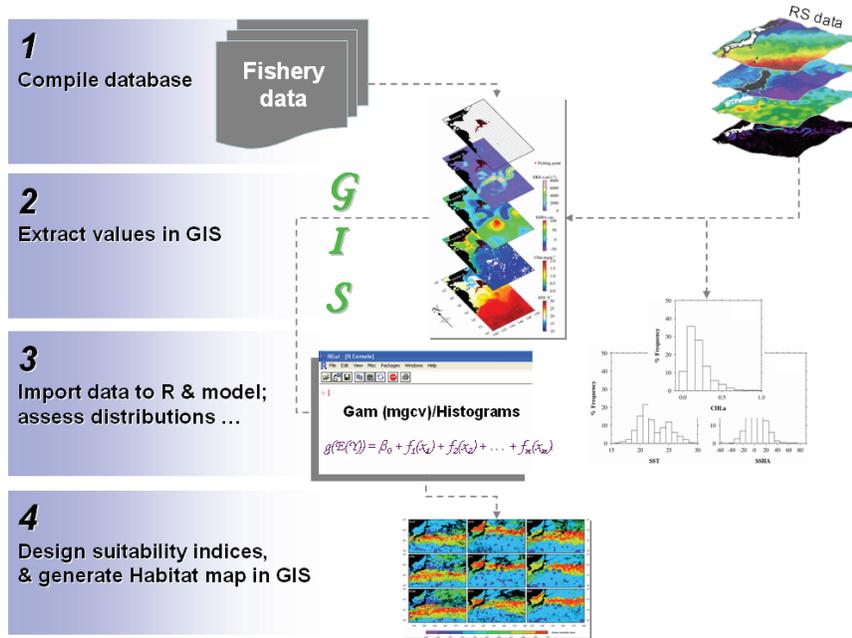


Figure 12.3 A schematic flow of methods and tools used in the analyses.

will mainly use ArcGIS 9.2 and some of the associated add-in programs that can be ported to the program. As utilization of oceanographic remotely-sensed imagery continues to grow, various add-in software continue to be designed that enable users to read the data directly into a GIS platform. That reduces the time used to process the data and convert them between different formats, thus granting ecologists more time to concentrate on their research. Two examples of such software are the Environment Data Connector (EDC) and the Marine Geospatial Ecology Tools (MGET) (Roberts et al., 2010). The EDC can be downloaded at <http://www.asascience.com/software/arcgistools/edc.shtml> while the MGET is available at <http://code.env.duke.edu/projects/mget>. Both have accompanying instructions for installation. They are useful for downloading remotely-sensed oceanographic data directly into ArcGIS and are appropriate especially for users who may not be conversant with other methods of reading such datasets. Once correctly installed, they are fairly easy to use.

### 12.3.4 Fisheries data

Fisheries data are useful mainly for indicating occurrence and abundance of a species in a certain area. Here we use fishery data from skipjack tuna fishing vessels in the western North Pacific from March to November 2004. The data are comprised of latitude and longitude positions, and catch per unit effort (CPUE). By mapping these data onto remotely-sensed images at corresponding time scales, they can

reveal the conditions under which catches were made. They were also used to make a generalized additive model (Wood, 2006) from which ranges of habitat variables important for skipjack tuna habitat were derived. Further reading on GAMs and their applications in fisheries work using remotely-sensed data can be obtained from Wood (2006), Valavanis et al. (2008), and Mugo et al. (2010), among others.

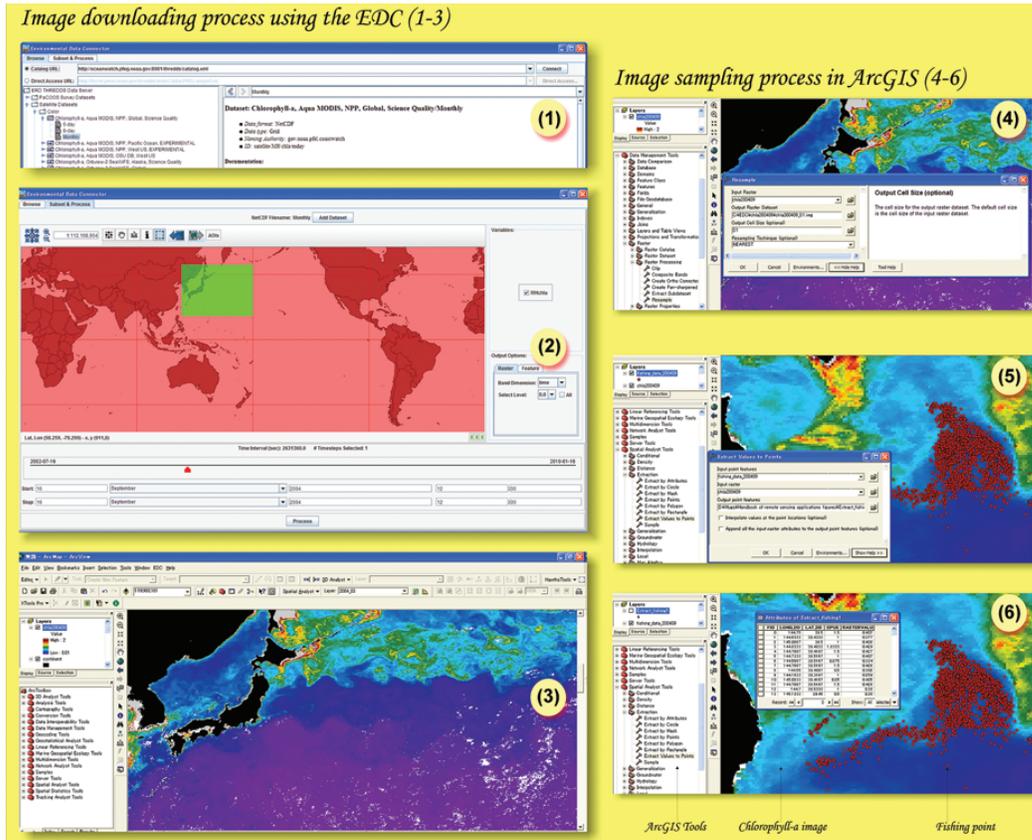
### 12.3.5 Remotely-sensed environmental data

We will use four types of remotely-sensed environment data, sea surface temperature (SST), surface chlorophyll concentration (chl-*a*), sea surface height anomalies (SSHA) and eddy kinetic energy (EKE) derived from geostrophic velocities. Each of these variables can be important indicators of the habitat of pelagic species. There are different ways of analyzing satellite datasets, given their spatial and temporal resolutions. Considering the temporal scale, one way would be to use the individual satellite passes for a certain variable, which can differ from hours to days depending on the repeat cycle. Another way would be to work with temporally-averaged data, either daily, 3 days, 7 days, 8 days, monthly etc, depending on the objective of the work at hand. Data averaging is commonly used to minimize instances of missing data due to weather conditions (clouds or rain) or instrument malfunction. Here we consider weekly- and monthly-resolved environment data in order to have (1) a relatively high temporal resolution to observe fishing fleet distribution (weekly scale) and (2) good coverage especially for SST and chl-*a* data (monthly-averaged data).

Working with ArcGIS 9.2 (and above), a relatively convenient way of downloading satellite datasets would be to use the Environment Data Connector tool or the MGET. In principle, these tools connect to remote databases (using the internet) and download data according to user specified input. Here we will illustrate briefly the process of downloading and sampling raster (image) data using the EDC. It is assumed that the user has already installed the tool and can access it from ArcGIS. For a step by step process on how to download a chlorophyll image, refer to Figure 12.4, steps 1-3. Steps 4-6 can be used to resample the image from one resolution value to another, and extract geo-physical values from the image using a set of known latitude-longitude positions.

**Step 1:** Connect to online databases using EDC and select the type of satellite data set to download. For example, to download monthly chlorophyll-*a*, select "Satellite datasets", "Colour", and select an ocean-colour dataset that suits your work. A brief description about the dataset is also given as metadata.

**Step 2:** Select the spatial extent and temporal resolution for the selected dataset. Click "process" to download data. In this case, the western North Pacific (18-50°N; 125-180°E) is selected for September, 2004.



**Figure 12.4** The process of downloading satellite data into ArcGIS using the EDC (1-3) and subsequent re-sampling of the data and extraction of geo-physical values corresponding to fishing locations. The processes are illustrated using a chlorophyll-*a* image and can be replicated with other satellite datasets such as SST or SSA.

**Step 3:** In the resulting raster image, BLACK represents land while WHITE is missing data.

**Step 4:** Use the ArcGIS ToolBox to resample the data to a desired resolution by selecting; "Data management tools", "Raster", "Raster processing" and "Resample". Complete the dialog box to finish the process.

**Step 5:** Overlay the chlorophyll-*a* image with fishing locations and sample (extract) the pixel values corresponding to the latitude-longitude positions. On the ArcGIS ToolBox, select "Spatial Analyst Tools", "Extraction", "Extract values to Points", complete the resulting dialogue box to sample the image.

**Step 6:** The results of the extraction process are a table showing the latitude-longitude positions of fishing locations and the corresponding chlorophyll-*a* values at those locations. These data can then be exported to Excel or any other software

	A	B	C	D	E	F	G	H	I
1	Longitude	Latitude	YEAR	MONTH	DAY	CPUE	SST	CHLA	SSHA
2	142.883	39.283	2004	9	1	0.500	19.936	0.306	-6.22
3	143.283	38.500	2004	9	1	0.500	20.617	0.389	-14.7
4	142.933	39.300	2004	9	1	3.667	20.027	0.279	-6.22
5	143.150	39.317	2004	9	1	1.833	19.956	0.284	-10.476
6	143.017	38.100	2004	9	1	0.500	22.125	0.265	9.151
7	143.167	38.433	2004	9	1	2.333	19.712	0.415	-14.711
8	143.233	38.367	2004	9	1	2.000	21.730	0.283	-14.7
9	143.133	38.450	2004	9	1	0.833	19.778	0.373	-14.7
10	143.283	38.433	2004	9	1	1.600	21.457	0.360	-14.7
11	143.133	38.467	2004	9	1	2.000	19.778	0.373	-14.7
12	143.133	38.467	2004	9	1	2.667	20.524	0.322	-14.7
13	143.450	39.100	2004	9	1	0.833	20.841	0.265	-14.7
14	143.450	38.867	2004	9	1	0.500	20.629	0.280	-10.4
15	143.067	39.133	2004	9	1	1.500	20.907	0.235	-12.5
16	143.533	39.283	2004	9	1	1.500	20.907	0.235	-12.5

**Figure 12.5** A sample fisheries environment database showing the spatial information (longitude and latitude), the temporal information (year, month and day), fishery information (CPUE) and environmental information derived from remotely-sensed images (SST, chl-*a* and SSHA). Such a database is useful for modelling the habitat conditions of the species under study.

for further analysis.

Re-sampling the image resolution is an important step, especially in cases where the datasets in use have different spatial resolutions. Harmonizing the resolution before analyzing the data further ensures that the pixel values for all images have the same "dimensions". These steps assume that the user has some basic knowledge of using ArcGIS (ArcView), with at least the Spatial Analyst extension. To obtain data for other variables (SST and SSHA) repeat these steps for each respective image. For this exercise, we download weekly and monthly datasets for each parameter. Utilization of the MGET tool is not illustrated here but it is fairly straight forward. For example, we can use MGET to download weekly geostrophic current velocity images,  $1/3^\circ$  resolution ( $u$  and  $v$  components) as ArcGIS rasters from AVISO. The  $u$  and  $v$  weekly rasters are then used to calculate EKE with the Raster Calculator function in Spatial Analyst extension (ArcGIS 9.2) using Equation 1 (Robinson, 2004). Further, we can average the weekly EKE rasters into monthly data, using the Raster Calculator function in Spatial Analyst extension, by simply adding the rasters and dividing by the total number of rasters. The resulting raster can then be subjected to steps 4 - 6 in Figure 12.4.

$$\text{EKE} = \frac{1}{2}(u^2 + v^2) \quad (12.1)$$

Since we have used the same latitude and longitude positions to sample/extract values from four different monthly images, it is possible to combine the values extracted from each image into one final database as shown in Figure 12.5.

## 12.4 Demonstration Section

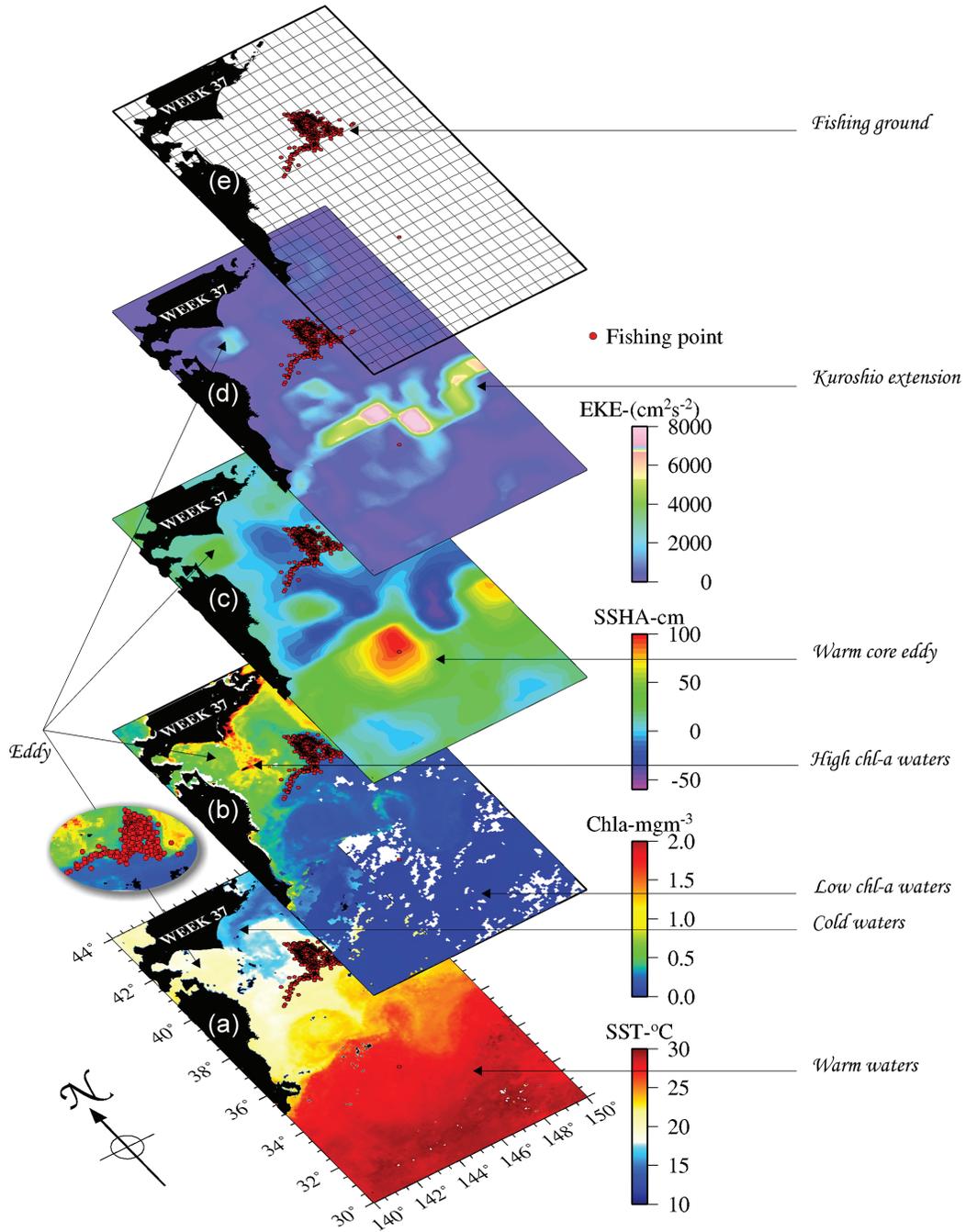
Thermal and ocean-colour fronts, meso-scale phenomena such as warm and cold core eddies, and ocean currents are key features that determine the distribution of pelagic fish. Since the advent of ocean satellite remote sensing, it is possible to monitor the development of these features at relatively large spatial scales and hence assess their effect on fish habitat. Information from such studies has had applications in operational fisheries oceanography and marine resource conservation.

To enhance our understanding of satellite image interpretation in relation to tuna ecology, we will first consider one set of four images (SST, chl-*a*, SSHA, EKE), each of which is overlaid with weekly-resolved fishing locations (Figure 12.6). All the images are of the same week (week 37). Figure 12.6a is a SST image, colour coded from blue to red. The red represents warm waters while blue shows cold waters or lower temperatures. The warm waters become progressively cooler as we move northwards, where they "meet" the southward flowing cold waters driven by the Oyashio Current. A northward flowing "stream" of warm waters (41°N, 146°E), 18-20°C (refer to the SST image colour bar) has made an "incursion" into the cold water region. Skipjack tuna fishing locations are also situated within this northward flowing stream of warm waters, indicating the temperature range within which the fish were found.

In Figure 12.6b, the same fishing locations as in Figure 12.6a are overlaid on a chlorophyll-*a* image. The blue areas of this image show low chlorophyll waters while the green to red colour represents relative high chlorophyll-*a* waters. It is interesting to note that the low chlorophyll or oligotrophic waters correspond to warm water areas while relatively eutrophic waters correspond to cold waters in the north. In this case, skipjack tuna fishing locations are aligned along the relatively oligotrophic waters but right at the "edge" of high chlorophyll waters. This "edge" appears to divide two water masses, a warm and oligotrophic water mass from a cold and eutrophic water mass, a phenomenon commonly referred to as a "front". Fronts have been shown to be one of the mechanisms that aggregate tuna.

Figure 12.6c illustrates fishing locations overlaid on a SSHA image. Sea surface height anomaly data are useful in showing meso-scale variability in the ocean. This involves the distribution of eddies and surface currents. In this image, areas with positive anomalies are shown as green to red, which are likely to indicate presence of warm core eddies. Dark blue to purple areas indicate areas with negative anomalies which represent cold core eddies. The distribution of fishing locations points to a pattern where the locations are associated predominantly with zero to positive anomalies and not much with the negative anomaly areas.

The EKE image (Fig. 12.6d) presents information on eddy kinetic energy which can tell us more about presence of strong eddies or fast flowing currents. For instance, the Kuroshio Current and Extension are clearly visible from this image. Such features also influence tuna migration and are thus important to consider

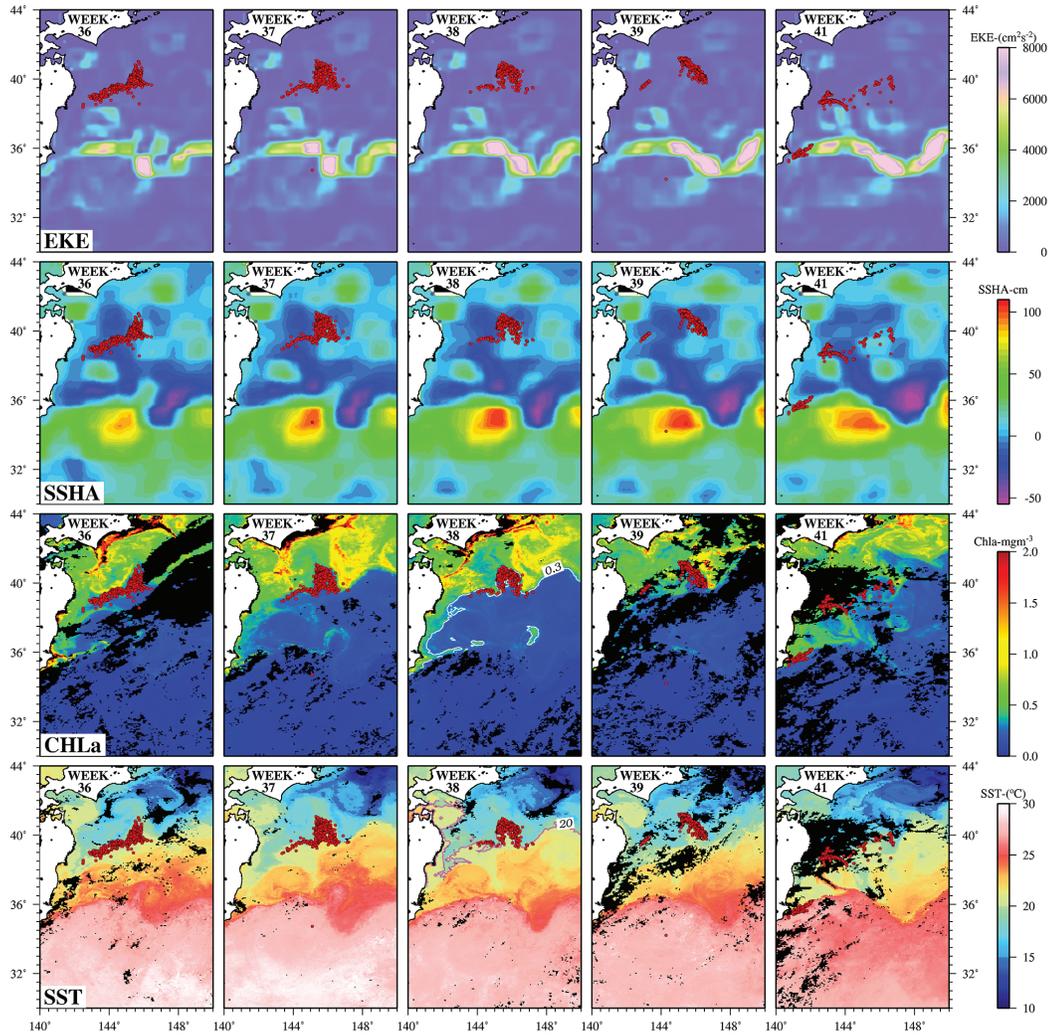


**Figure 12.6** Four images (SST, chl-a, SSH and EKE), on the same time scale and overlaid with daily fishing locations for the same period.

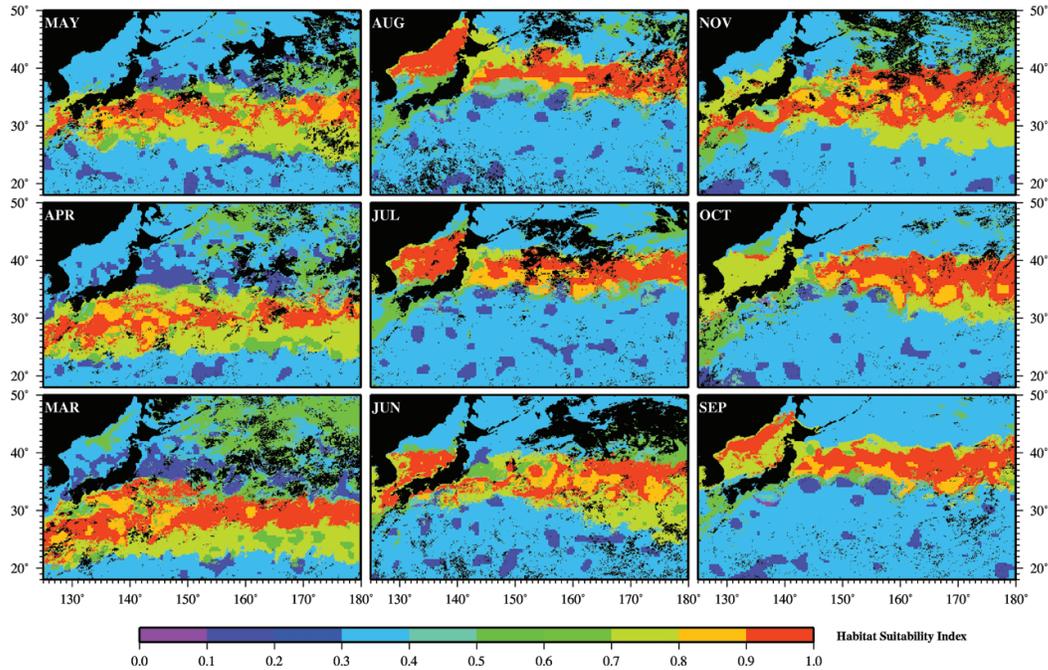
while looking at distribution of tuna resources relative to surface features. The relationship with the fishing locations during this week is not that apparent, but that information may be clearer with further analysis. A warm core eddy south of Hokkaido can be identified from this image and in the previous images as well.

Figure 12.7 illustrates a series of weekly images (SST, chl-*a*, SSHA and EKE) from week 36 to 41 with an exception of week 40, in September 2004. Daily fishing positions corresponding to the respective image time scale are superimposed on the images as red dots. All the images are colour coded to facilitate easy interpretation. Missing data are shown in black. The set of images we discussed above is shown in the second column. By applying the same concepts discussed above to the other images, it is possible to interpret them as well. In week 38, contours (vector data) have been added on the SST and chl-*a* images, showing the mean environmental conditions on the fishing grounds. Temperature and ocean-colour fronts (gradients) are observable on these images. The fishing positions show a spatial pattern consistent with oceanographic features observable from the SST, chl-*a* and some SSHA images. Notably, the fishing positions appear consistent with the 20°C SST isotherm, which appears to be a good proxy for the 0.3 mg m<sup>-3</sup> chl-*a* isopleth (e.g. week 38).

Having discussed the relationships between fishing locations and the four environmental factors derived from remotely-sensed images, let us draw some ecological interpretations with reference to skipjack tuna. Temperature as a habitat signature may explain part of the observed spatio-temporal variability in skipjack tuna fishing set distribution. SST is known to influence tuna migration (Sund et al., 1981). Considering the distribution of fishing locations overlaid on SST and chl-*a* images (both averaged on the same time scale), it is apparent that the fishing positions were aligned on the warm and oligotrophic side of the front. There are no fishing positions on the cold and eutrophic waters (mainly Oyashio waters). Relatively low chlorophyll waters, especially on the frontal edges of warm oligotrophic waters, have both physiological and trophic implications for skipjack tuna. It enables skipjack tuna to locate prey and forage on the periphery of highly productive frontal or upwelling zones, and also stay within tolerable temperatures (Ramos et al., 1996). Tunas are predominantly visual predators, feeding opportunistically and unselectively on micro-nekton and therefore highly turbid waters are unsuitable for them (Ramos et al., 1996; Kirby et al., 2000), while extremely oligotrophic waters would contain little food (Sund et al., 1981). A study in the western North Pacific on skipjack tuna ecology by Nihira (1996) showed that stomach contents of skipjack tunas caught near the front of a warm streamer were twice to five times heavier than those caught at the center of the warm streamer and thus concluded that the front was the most suitable feeding place. Fiedler and Bernard (1987) also found that skipjack tuna aggregated on the warm edge of waters near cold and productive water masses off southern California. Oceanic fronts are broadly understood to mark the boundary between two different water masses, manifested as regions of



**Figure 12.7** Spatial distribution of skipjack tuna fishing fleet in September 2004 overlaid on weekly averaged sea surface temperature (SST), sea surface chlorophyll (chl-*a*), sea surface height anomalies (SSHA) and eddy kinetic energy (EKE), off Japan in the western North Pacific. The fishing locations were in phase with the 0.3  $\text{mg m}^{-3}$  chlorophyll-*a* and 20 $^{\circ}\text{C}$  SST contours.



**Figure 12.8** A habitat suitability map computed from monthly averaged SST, chl-*a*, SSHA and EKE whose habitat ranges for skipjack tuna were derived using a GAM. This demonstrates some of the products that can be derived from remotely-sensed oceanographic data. Land or areas with no data are shown in black.

strong horizontal gradients in temperature, salinity, chlorophyll and concentration of zooplankton and micronekton (Olson et al., 1994; Kirby et al., 2000).

The spatial relationship of fishing locations with SSHA images, though not as apparent as that of SST and chl-*a* images, points to the presence of warm and cold-core eddies near fishing locations. The fishing locations appear oriented on the periphery of warm core eddies. The EKE images also confirm the presence of eddies observed on SSHA images. The EKE images also clearly show the path of the Kuroshio Current. Aggregation of tuna along eddy edges has been attributed to nutrient injection or entrainment to the euphotic zone (Olson, 1991) and development of phytoplankton blooms which trigger secondary production (Bakun, 2006). This attracts nekton, with a net effect of aggregation of apex predators to forage on the lower trophic level organisms around the eddy edge (Ramos et al., 1996; Fonteneau et al., 2009).

The data sampled from the satellite images can be compiled into a database that describes the conditions where fishing is taking place, as is shown in Figure 12.5. Data from such a database can be used to generate models that provide more information on the habitat of the species in question. Different types of models can be applied depending on the objective of the work. In this case, we highlight the

application of a generalized additive model (GAM) (Wood, 2006), from which the ranges of environmental variables with a positive effect on CPUE were determined (results from GAMs are cited but not presented here). The terms derived from the GAM can be applied on monthly averaged SST, chl-*a*, SSHA and EKE images to derive a simple habitat index map shown in Figure 12.8. This can be done using tools in the Spatial Analyst extension of ArcGIS 9.2 (or higher). From this figure, it is possible to visualize the annual displacement of skipjack tuna habitat from the south to the north (March to August/September) and later southwards in October and November. Figures were done using GMT 4.4.0. Such results are important for assessing habitat distribution at a synoptic scale, which is vital for ecosystem based management.

## 12.5 Questions

**Q 1:** With reference to the SST images shown in Figure 12.7 (weeks 36 and 38-41), why do you think skipjack tuna fishing locations appear on the yellow to red parts of the image and not the blue parts? NOTE: the SST image is colour coded; the red shows warm waters while light to deep blue shows cold waters.

**Q 2:** With reference to the chl-*a* images shown in Figure 12.7 (weeks 36 and 38-41), and also in light of the discussion above, why do you think skipjack tuna fishing locations appear on the blue parts of the image and not the green to red areas? NOTE: the chl-*a* image is colour coded; the blue shows low chlorophyll waters which also correspond to warm waters while green to red shows relatively high chlorophyll waters which also correspond to cold water masses.

**Q 3:** What important information can we derive from altimetry data such as sea surface height anomalies? How is that information relevant to tuna ecology?

## 12.6 Answers

**A 1:** Skipjack tuna are warm water fish, and also aggressive feeders. Therefore SST can act as an index of their distribution especially when they have migrated towards higher latitudes where waters get progressively colder. They appear to track warm waters and avoid the cold waters below 17°C. They are also found on the oligotrophic side of fronts which are rich in food as a result of high primary and secondary production induced by upwelling.

**A 2:** Skipjack fishing locations appear not only in the low chlorophyll areas, but also in areas associated with steep colour gradients which indicate ocean-colour fronts. Such areas are productive zones that provide feeding opportunities for skipjack tuna. However, the tuna remain in relatively low chlorophyll waters where turbidity

is less, and visibility is good. This enhances their ability to locate food. Tunas are known to locate their food by sight. The relatively oligotrophic waters also happen to be regions with tolerable temperatures for the species.

**A 3:** Altimetry is a technology that measures height. Satellite altimetry measures the time taken by a radar pulse to travel from the satellite antenna to the surface and back to the satellite receiver. Combined with precise satellite location data, altimetry measurements yield sea-surface heights. Altimetry data are important at revealing meso-scale variability in the oceans. From these data, it is possible to track movement of eddies and strong currents in the oceans. Such features are important for exchange of heat and nutrients in the oceans, and thus can influence productivity of adjacent water masses and by extension the marine biota associated with them. Therefore, at times, movement of meso-scale features can affect the distribution of predators such as tuna. It follows that tracking such features through satellite remote sensing can provide information on ocean circulation and the associated biotic interactions. Further, altimetry data may provide a "glimpse", even though not as detailed, of oceanographic conditions where satellite surface temperature or surface chlorophyll data are missing due to cloud cover.

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### 12.7.1 Suggested Reading

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## **12.8 Glossary of Technical Terms**

Chl- <i>a</i>	Sea Surface Chlorophyll
CPUE	Catch Per Unit Effort
EDC	Environment Data Connector
EKE	Eddy Kinetic Energy
GAM	Generalized Additive Model
GIS	Geographic Information Systems
GMT	Generic Mapping Tools
MGET	Marine Geospatial Ecology Tools
SSHA	Sea Surface Height Anomalies
SST	Sea Surface Temperature
WCR	Warm Core Ring