論文の内容の要旨

A Novel Approach for Monitoring Small-Scale Fisheries with GPS, GIS, and Remote Sensing Techniques

(GPS，GIS，リモートセンシングを用いた小規模漁業モニタリングの新しいアプローチ)

ナゼイル　ムハンマド　アブドルワヒード　アルアブシ

Small-scale fisheries worldwide are less investigated although they provide most of the production from the sea to local people and secure employment for 98% of fifty one million fishers in the world. Most of these fisheries are located in developing countries where scientific researches in fisheries management lack official support and fisheries scientists are underqualified. Accordingly, it is difficult for scientists and fishery managers in these countries to apply the same approaches used for large-scale fisheries in developed countries. Tropical small-scale fisheries are highly heterogeneous with respect to a wide variety of fisheries characteristics. It is necessary to examine the heterogeneities of small-scale fisheries, which haven't been investigated. For this purpose, a novel approach using GPS, GIS and remote sensing techniques was developed in this study. Yemen's small-scale fisheries as an ideal type of a small-scale fishery were chosen as a case study to explore the potential of the approach for monitoring of small-scale fisheries. The recent decline of fish resources of Yemen coupled with uncontrolled growth of fishing fleets are major obstacles for development of sustainable fisheries. Both stock status and current exploitation levels of major fisheries are unknown. Lack of scientific researches and effective management policies jeopardizes the sustainability of Yemeni small-scale fisheries and coastal ecosystems. In order to conserve the coastal fisheries resources and ecosystems on which coastal inhabitants are dependent for subsistence, it is necessary to determine the exploitation levels of fisheries resources. Spatio-temporal distributions of fishing efforts and catch per unit effort (CPUE) can provide a detailed picture of exploitation patterns and pressure levels on different fish stocks. The details are described as follows.

The study describes the status of Yemeni fisheries and highlights their current problems and priority research areas. It also analyses the different components of the fisheries management system of Yemen and highlights its strengths and weaknesses. Yemen's coastline exceeds 2,500 km extending along the Red Sea, Gulf of Aden and Arabian Sea. Stock status of commercially exploited fish species is unknown and no active management plans enforced anywhere in Yemen. Furthermore, fishing efforts, namely number of fishing boats, have increased four-fold between 2000 and 2010 while the CPUE has decreased significantly during the same period. According to official statistics, total fish production of Yemen has reached a peak of 256,000 tons in 2004 and thereafter dropped to 180,000 tons in 2007 and to 127,000 tons in 2008. To ensure sustainable exploitation in such data poor situations, it is greatly needed to study the characterization of fishing effort and fishermen's use of resources and fishing grounds. This study aims to develop a novel approach for monitoring small-scale fisheries and their CPUEs, integrating GPS acquired location data of fishing boats, GIS that relate position data with catch and environmental data and remote sensing techniques that provide environmental data. Using this approach, we described the spatio-temporal distribution of fishing grounds and how the fishing grounds are

formed and influenced by the environmental conditions and the implications for fishery management were explored. This study selected two representative small-scale fisheries from the Red Sea of Yemen.

The novel approach developped here is designed for obtaining positions of small-scale fishing boats and analysing fishing grounds with GPS, GIS software and satellite images of sea surface temperatures and chlorophyll monitored by MODIS satellites and provided by National Aeronautics and Space Administration, United State of America. The GIS software used bottom topography data of ETOPO1 for fishing ground analysis. The ETOPO1 is a one arc-minute global relief model of Earth's surface that integrates land topography and ocean bathymetry provided by National Geophysical Data Center, United States of America. Forty GPS loggers were used and one GPS logger was given to each voluntary boat, which reported catch of each trip during acquisition of boat position with the logger. These data were analysed with GIS software (ArcGIS 10.0, ESRI). Catch data were collected on each trip, which include the catch composition by species and weight.

The novel approach was applied to a case study of Indian mackerel (*Rastrelliger kanagurta*) fisheries in Yemeni Red Sea to describe the spatio-temporal distribution of fishing grounds and to investigate the roles of environmental variables in the formation of fishing grounds and their dynamics in time and space. For this purpose, 20 GPS loggers were used to collect the data on boat location and speed at 5-seconds intervals for purse seine fishing gear targeting the Indian mackerel. The overall lengths of the boats belonging to the voluntary skippers were between 12 and 15 m. The fishers used purse seine nets, which had an average horizontal length of 407 m and vertical depth of 16.3 m. Fishing is conducted only during the nighttime between sunset and sunrise and one trip is confined to only one night and the fishing usually stops from day 7 to day 17 during the lunar nights. Twenty GPS loggers were used for eight months to collect the position data on the Indian mackerel fishery. Fishing hauls were easily recognized with boat speed recorded by the high resolution GPS recordings. The mean number of fishing hauls per day was 2.65±1.4 hauls/day and the mean hauling speed (encircling speed) was 13.2 m/s. The mean catch/haul and mean catch/day were 98.6±70.4 kg and 212.5±154.5 kg, respectively. Geospatial analysis using GIS and remote sensing data and bottom topography showed that fishing grounds of Indian mackerel were concentrated in high chlorophyll waters and along the SST fronts. Especially in October, most of the catch originated from areas in inshore waters inside two semi-enclosed bays. Inshore movement of Indian mackerel was synchronized with the highest annual chlorophyll concentration. This indicates a specific behaviour of this species, probably associated with spawning which occur around this period.

The novel approach was also applied to a case study of pharaoh cuttlefish (*Sepia pharaonis*) in Yemeni Red Sea to describe their spatio-temporal distributions. The overall lengths of most fishing boats targeting this species were 7-m. Fishers used a hook and line with artificial lures to fish cuttlefish. Data on more than 2000 fishing trips of 40 voluntary boats between June 2011 and May 2014 were collected by providing the voluntaries with GPS loggers. Boat positions were recorded using the GPS logger at 1-minute intervals for monitoring fishing activities of boats targeting pharaoh cuttlefish. Boat positions data were processed with the GIS software to remove non-fishing periods based on boat speeds below 3 km/hr because the boats were usually drifting while fishing. The catch of every trip measured at a landing port was divided on all the fishing points of the trip according to the time. Maps of the monthly and seasonal spatio-temporal distribution of CPUEs showed that a time series graph of monthly CPUE had two peaks, one in March/April and the other in August/September. The cuttlefish in the study area has two fishing seasons per year, the first started from mid-January until May and the second from July until September. Distribution of fishing activities was highly confined to shallow bottom depths between 0 and 20 m. Since *Sepia* sp. live in offshore waters and move to the coastal areas for spawning, this suggests that the two peaks in March/April and in August/September correspond to two spawning times for this species, which may produce two different cohorts of cuttlefish.

Essential information and knowledge on stock status are not available in most developing countries. Simple and inexpensive methods of fish abundance estimation are desired in such situations. This study developed a novel approach to monitor fishing effort distributions in time and space with the use of mobile GPS loggers. High-resolution data enable us to detect the exact fishing locations and to estimate fishing effort. The GPS data of purse seines have included a variety of helpful information. The diameter of fishing haul gives a good indication of the size of fishing gear used. After-haul drifting chart gave an indicator of wind speed and direction. Speed chart of fishing boat indicates the optimum speed for fishing efficiency. The high correlation between satellite derived chlorophyll and Indian mackerel distribution introduces opportunities to investigate the spatio-temporal distributions of this species and will aid to formulate management plans. The concentration of hauling locations around sea surface temperature fronts can be utilized to characterise the potential fishing zones and this will greatly minimize search costs and the time spent in the sea for fishers. The spatio-temporal distribution of CPUE of pharaoh cuttlefish revealed their aggregation sites and the coincident overfishing during this study. The results suggest the use of spatial and/or temporal ban on fishing for cuttlefish in the critical spawning and nursery areas of this species.

Finally, this study highlights the necessity of involvement of fishermen in the collection of data for scientific purposes. Fishing boats can play as platforms for data collection on the resource exploitation. This new approach will minimize research costs and give an opportunity to collect data on small-scale fisheries not only in developing countries but also in developed countries.