SCIENTIFIC COMMITTEE
SECOND REGULAR SESSION

7-18 August 2006
Manila, Philippines

SEAMOUNT RESEARCH PLANNING WORKSHOP REPORT, 20-21 MARCH 2006

WCPFC-SC2-2006/EB IP-5

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Seamount Research Planning Workshop Final Report

Report of the Seamount Research Planning Workshop held at the Secretariat of the Pacific Community, Noumea, New Caledonia, 20-21 March 2006

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Secretariat of the Pacific Community

July 2006

GEF Pacific Islands Oceanic Fisheries Management Project

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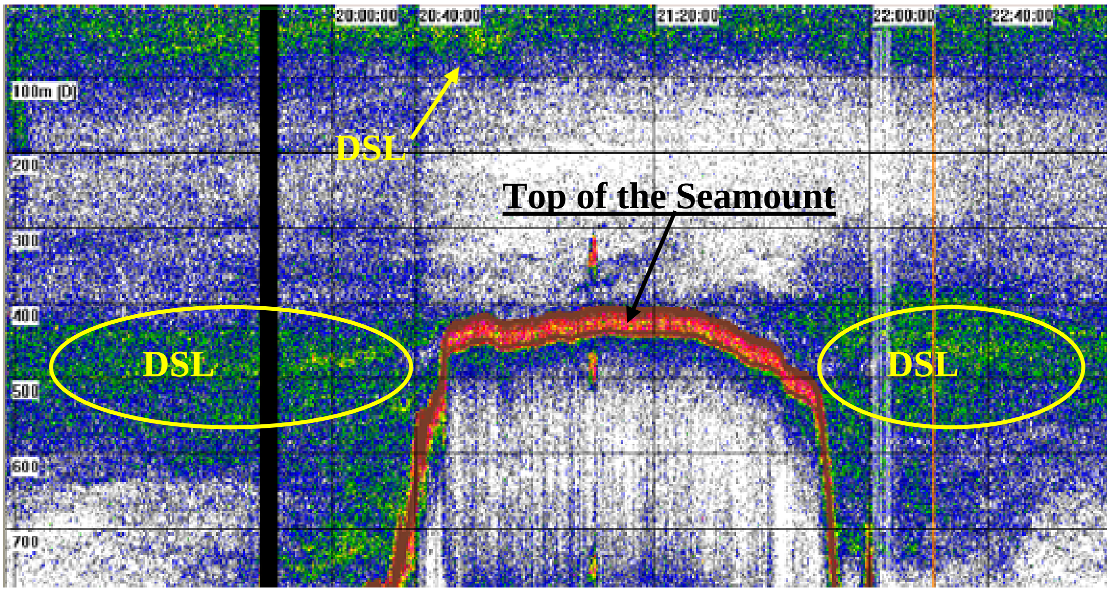
ACRONYMS and GLOSSARY

CENSEAM: CenSeam (a Global Census of Marine Life on Seamounts) is a program which brings scientists together from all continents of the world to improve understanding of seamounts ecosystems. Its mission is to determine the role of seamounts in the biogeography, biodiversity, productivity, and evolution of marine organisms, and to evaluate the effects of human exploitation on seamounts.
Website: http://censeam.niwa.co.nz/

CSIRO: The Commonwealth Scientific and Industrial Research Organisation is Australia's national science agency which works from sites across the nation and around the globe to deliver scientific solutions for industry, society and the environment.
Website: http://www.csiro.au/

DOQ: Deep Ocean Quest is a private company that provides marine logistics support for the marine science and filmmaking communities. DOQ's basic mission is to further knowledge and understanding of the oceans and marine resources with a view to raising the awareness of the need for their sustainable use.
Website: http://www.deepoceanquest.com/

DSL (Deep scattering Layer): Horizontal zone of living organisms, usually schools of fish, occurring below the surface in many ocean areas, so called because the layer scatters or reflects sound waves, causing echoes in depth sounders. The DSL tends to rise at night, and to descend during daytime. *(Source: Encyclopedia Britannica - FishBase Glossary)*



Sonar echoview on the Brittania Seamount, Eastern Australia
(Jock Young, Alistair Hobday and Tim Ryan (2004) Spatial Variations in micronekton distributions off East Australia from nets and acoustics. PFRP Principal Investigators Workshop November 29 - December 1, 2004.)

ECOTAP: ECOTAP is a programme funded by IRD which has been carried out from 1995 to 1998. Its goal was to improve the understanding of the behavior and distribution of tuna in the French Polynesian EEZ. For this, acoustic and fisheries studies were undertaken to characterize pelagic habitat in French Polynesia, to study the distribution of tuna and to estimate their abundance in the longline fishery.
Website: http://www.ird.fr/fr/actualites/fiches/2000/fiche115.htm

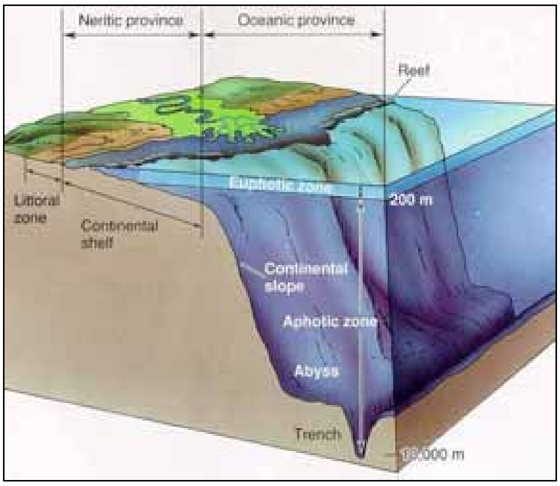
ENSO (El Niño Southern Oscillation): ENSO is a large scale climatic fluctuation of the tropical Pacific Ocean. These fluctuations are represented by the term “El Nino/ La Nina”, while changes in the atmosphere are known as the “Southern Oscillation”. Because these two cannot be separated, the term ENSO is often used. ENSO refers to both El Nino and La Nina. This fluctuation results from the dynamic and thermodynamic interactions among the atmosphere, oceans, and land surfaces; exactly what initiates an ENSO is unclear. It seems certain that pressure changes and wind currents play a vital role. Some researchers have implicated the greenhouse effect while others have attributed it to activity occurring on the ocean floor (*e.g.* earthquakes). *(Source: Encyclopedia - South Africa Weather Service)*

ETOPO2 (2-Minute Gridded Global Relief Data): ETOPO2 is a 2-minute worldwide bathymetry/Topography dataset provided by the US National Geophysical Data Center. It is a combination of several digital databases of seafloor and land elevations on a 2-minute latitude/longitude grid as:

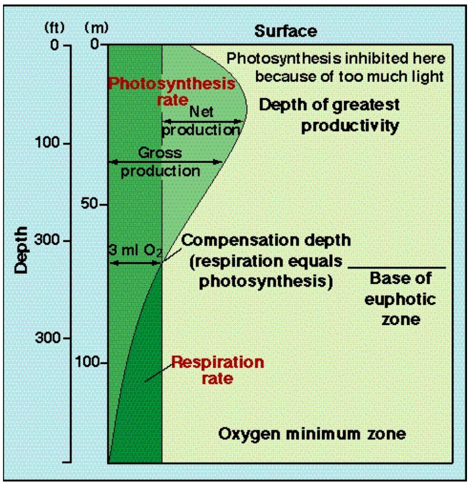
- Data from the work of Smith and Sandwell (1997), derived from satellite radar altimetry of the sea surface.
- Data from GLOBE project (Land topography).
- Data from IBCAO (International Bathymetric Chart of the Arctic Ocean)
- Data from DBDBV (Digital Bathymetric data Base Variable Resolution) and the older DBDB5.

(*Source:* *http://www.ngdc.noaa.gov/mgg/fliers/01mgg04.html#GriddedF*)

Euphotic zone: The surface waters of the sea where enough light penetrates for photosynthesis to occur, down to about 80 meters. The depth of the euphotic zone varies with the water’s extinction coefficient, the angle of incidence of the sunlight, length of day and cloudiness. *(Source: FishBase Glossary)*



Source: http://dragon.seowon.ac.kr/~bioedu/bio/ch46.htm



Source: http://www.geology.wmich.edu/gillespie/g322/Chapters/otln14.htm

FADIO: “Fish Aggregating Devices as Instrumented Observatories of pelagic ecosystems” is a 39 month research project (January 2003 – March 2006) funded by the DG Research of the European Union, gathering eight European partners and one American partner. The main objective of this programme is to develop new observation instruments to better study the behavior and abundance of pelagic fish (in particular tunas): new electronic tags and new instrumented FADs. This project conducted several oceanographic sea surveys with modern instruments in order to collect some information on the behavior of species aggregated around drifting FADs, especially tropical tunas.
Website: http://www.fadio.ird.fr/

FFA: Forum Fisheries Agency is an organisation set up to provide expert fisheries management and development advice and services to member countries of the Pacific. It comprises 17 member governments. Its mission is to enable Member Countries to manage, conserve and use tuna resources in their Exclusive Economic Zones and beyond, through enhancing national capacity and strengthening regional solidarity.
Website: http://www.ffa.int/

GEF: The Global Environment Facility is an independent financial organization that provides grants to developing countries for projects that benefit the global environment and promote sustainable livelihoods in local communities. GEF grants support projects related to biodiversity, climate change, international waters, land degradation, the ozone layer, and persistent organic pollutants. Its implementing agency is UNDP (United Nations Development Programme).
Website: http://www.gefweb.org

IOZ: Institute Of Zoology is the research division of the Zoological Society of London. It is a government-funded research institute specializing in scientific issues relevant to the conservation of animal species and their habitats.
Website: http://www.zoo.cam.ac.uk/ioz/

IRD: Institute for the Research and Development is a French public science and technology research institute which performs research and manages scientific programmes contributing to the sustainable development of the countries of the South, with an emphasis on the relationship between man and his environment. IRD was previously named ORSTOM.
Website: http://www.ird.fr

IUCN: The International Union for the Conservation of Nature and Natural Resources also named the World Conservation Union is a membership organization which brings together states, government agencies, non-governmental organizations and scientists and experts from many countries. Its mission is to influence, encourage and assist societies throughout the world to conserve the integrity and diversity of nature and to ensure that any use of natural resources is equitable and ecologically sustainable. For that it supports and develops cutting-edge conservation science; implements this research in field projects around the world; and then links both research and results to local, national, regional and global policy by convening dialogues between governments, civil society and the private sector.
Website: http://www.iucn.org

MUSORSTOM: Musorstom is a collaborative programme between the French National Museum of Natural History and Institute for the Research and Development (Previously named ORSTOM). It organizes scientific cruises to explore and assess the benthic marine fauna in the tropical Indo-Pacific area.
Website: http://www.mnhn.fr/musorstom/index.html

NIWA: National Institute of Water and Atmospheric Research is a New Zealand research organization which provides environmental research and consultancy services. It creates and delivers science-based services and products that enable people and businesses to make best use of the natural environment and its living resources, and derive benefits from them in a sustainable manner.
Website: http://www.niwa.co.nz/flash/

OFM Project: The Oceanic Fisheries Management Project is funded by GEF to achieve global environmental benefits by enhanced conservation and management of transboundary oceanic fishery resources in the Pacific Islands region and the protection of the biodiversity of the Western Tropical Pacific Warm Pool Large Marine Ecosystem. It is executed by the FFA in con-junction with the SPC and the IUCN.
Website: http://www.ffa.int/gef/

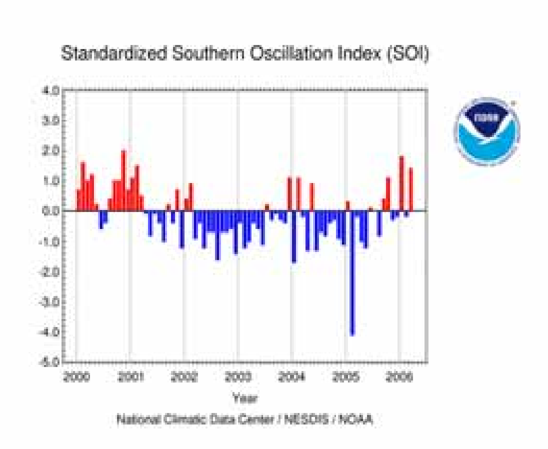
OFP: The Oceanic Fisheries Programme of the Secretariat of the Pacific Community, formerly known as the Tuna and Billfish Assessment Programme (TBAP) was established by the 1980 South Pacific Conference to continue the work initiated by its predecessor project, the Skipjack Survey and Assessment Programme (SSAP). The OFP receives funding from different governments and funding agencies to provide member countries with the scientific information and advice necessary to rationally manage fisheries exploiting the region's resources of tuna, billfish and related species.
Website: http://www.spc.int/oceanfish/

PFRP: Pelagic Fisheries Research Program was created to provide scientific information on pelagic fisheries to the Western Pacific Regional Fisheries Management Council (USA) for use in development of fisheries management policies. It is administered by the Joint Institute for Marine and Atmospheric Research within the University of Hawaii's School of Ocean and Earth Science and Technology.

Website: http://www.soest.hawaii.edu/PFRP

SPC: The Secretariat of the Pacific Community is an international organization which works in partnership with its members, other organizations and donors to deliver priority work programmes to member countries and territories of the Pacific. Its mission is to help Pacific Island people make and implement informed decisions about their future. Its current work programmes focuses on land resources, marine resources and social resources.
Website: http://www.spc.int/

SOI (Southern Oscillation Index): It has been found that the cyclic warming and cooling of the eastern and central Pacific can be seen in the sea level pressure in the region. In particular, when the pressure measured at Darwin, Australia is compared with that measured at Tahiti, French Polynesia, the differences between the two can be used to generate an "index" number. So SOI is calculated from the monthly or seasonal fluctuations in the air pressure difference between Tahiti and Darwin. A positive number indicates La Niña (eastern tropical Pacific ocean cooling) and a negative number indicates El Niño (or ocean warming).
(Source: NOAA, Climate Diagnostics Center – Australian Government, Bureau of Meteorology)



1. Introduction

Context of the study

There are a large number of seamounts in the Western Tropical Pacific (WTP) and the possible impact of fishing around seamounts is a major global environmental concern. Seamount ecosystems have been characterized by a high degree of endemism, they support vulnerable benthic communities (corals, sponges), including long-lived, slow-growing fish species and they are thought to aggregate pelagic species and to support a mix of pelagic species that differs from the open ocean.

Deep sea bottom trawling can have destructive effects on seamount habitats and ecosystems; there is currently no known deep sea bottom trawling in the WTP but the potential risks from future fishing are now subject to pre-emptive management.

Concerns about the impact of pelagic fishing around seamounts include the possibility of:

1- higher proportions of juvenile fish in catches
2- higher levels of catches of some bycatch species (species of special interest such as sharks, marlins, or species locally important for food security such as wahoo)
3- higher rate of interaction with fishing gear and then possible higher mortality of turtles, seabirds and marine mammals
4- trophic impacts due to sharing of prey between pelagic and demersal species due to vertical migration of some prey species

Despite their importance, the relationships between seamounts, pelagic fishing and pelagic species are not well understood.

The OFM project

In response to this, SPC in collaboration with the World Conservation Union IUCN, will conduct studies on the ecology of seamounts in relation to pelagic fisheries in the Western Tropical Pacific as part of the Pacific Islands Oceanic Fisheries Management Project (OFM project) funded by the Global Environment Facility (GEF) (Annex 1). The objective of this particular part of the OFM project is to acquire enhanced understanding of the ecology of seamounts in relation to pelagic fisheries in order to assess the need for, and utility of, seamount-specific management measures. It requires assessment of:

1- the impacts of seamounts on aggregation and movement of pelagic species
2- the pelagic fisheries impacts on the seamount (biodiversity and habitat).

To acheive these objectives, several activities have been identified:

1- Hold seamount activity planning and review workshops,
2- Describe seamounts and analyse historical fishing patterns around seamounts,
3- Collect data at selected seamounts, including tagging and trophic sampling,
4- Support national scientist participation in a benthic biodiversity survey.

The project officially started in November 2005 for five years, and the first seamount research planning workshop gathering seamount benthic and pelagic experts took place at the Secretariat of the Pacific Community in Noumea, New Caledonia on the 20-21 March, 2006.

The Seamount Research Planning workshop

The objective of the workshop was to plan the research activities on the ecology of seamounts in relation to pelagic fisheries in the Western Tropical Pacific.

A major subject of discussion was the design of a sampling programme to collect physical/biological oceanographic data and benthic and pelagic samples to characterize the seamounts and the pelagic ecosystem around seamounts and to determine the relationships between seamounts and pelagic fisheries.

The first day of the meeting was dedicated to presentations by some of the participants. The second day was devoted to a general discussion on the ecology of seamounts, their relation to pelagic fisheries and sampling issues along the lines of the agenda provided to the participants (Annex 2).

This document reports on the presentations given and the various subjects discussed during the seamount research planning workshop and particularly the implementation of seamount research activities under the OFM project.

2. Participants and presentations

The meeting was opened by John Hampton (SPC Oceanic Fisheries Programme Manager) who welcomed participants to Noumea and thanked them for contributing their time to participate in the meeting.

The participants (Table 1) then introduced themselves to the group and gave a brief description of their expertise and their role in the project.

Table 1. List of participants and their affiliation.

Participants	Organisation	Country	E-mail
Jock Young	CSIRO – Hobart	Australia	Jock.Young@csiro.au
Malcolm Clark	NIWA – Wellington	New Zealand	m.clark@niwa.co.nz
Alex Rogers	IOZ / IUCN	United Kingdom	Alex.Rogers@ioz.ac.uk
David Itano	PFRP, University of Hawaii	USA	dgi@hawaii.edu
Barbara Hanchard	FFA	Solomon Islands	Barbara.hanchard@ffa.int
Philippa Jane Cohen	Ministry of Fisheries	Tonga	pipcohen@tongafish.gov.to
Bertrand Richer de Forges	IRD – Noumea	New Caledonia	Bertrand.Richer-de-Forges@noumea.ird.nc
Valerie Allain	SPC/OFP – Noumea	New Caledonia	valerieA@spc.int
Bruno Leroy	SPC/OFP – Noumea	New Caledonia	brunol@spc.int
Steve Beverly	SPC/CFP – Noumea	New Caledonia	SteveB@spc.int
Adam Langley	SPC/OFP – Noumea	New Caledonia	AdamL@spc.int
David Kirby	SPC/OFP – Noumea	New Caledonia	davidK@spc.int
John Hampton	SPC/OFP – Noumea	New Caledonia	JohnH@spc.int
Julie-Anne Kerandel	SPC/OFP – Noumea	New Caledonia	julieannek@spc.int

Valerie Allain gave the first presentation, which provided an overview of the OFM project and the *Ecology of seamounts in relation to pelagic fisheries* component. Three presentations related to existing studies on seamounts followed and were presented by Bertrand Richer de Forges on the work conducted by IRD in the Pacific region, by Jock Young on the CSIRO studies in eastern Australia and by David Itano on the work conducted around Hawaii archipelago. Two presentations on studies and sampling cruises under development ended the presentation day and were presented by Bruno Leroy on the Papua New Guinea Tagging Project and by Alex Rogers on the Tui Delai Gau cruises in the South Pacific. An abstract of each presentation is provided hereunder.

Valerie Allain, (SPC – Noumea, New Caledonia)

The seamount research planning workshop has been organised in the context of the GEF funded Pacific Islands Oceanic Fisheries Management Project (OFM project) implemented by SPC and FFA in collaboration with IUCN. The first objective of this project is to improve the understanding of oceanic fish resources and their pelagic environment through ecosystem monitoring and analysis. The project has a particular interest in the ecology of seamounts in relation to pelagic fisheries in order to assess the need for, and utility of, seamount-specific management measures.

The number of potential seamounts in the global ocean has been estimated at >100,000 However, the precise location of most has not been confirmed as very few have been studied *in situ*. This is despite the existence of several sources of information of which the Kitchingman and Lai (2004) dataset is the most complete, though it is largely unvalidated and contains some errors. Pelagic fisheries in the western Pacific catch bigeye, skipjack, yellowfin and albacore using mainly purse seine and longline fishing gear. Catch data are collected by SPC (effort, catch, species composition, length). To determine the impact of seamounts on pelagic fisheries it is necessary to establish the sphere of influence of the seamount both in vertical and horizontal dimensions. Using fisheries data and seamount positions, it will be possible to examine if seamounts aggregate fish in large quantities or particular species or specific sizes of fish. To determine the impact of pelagic fisheries on seamounts, 2 ecosystem components have to be considered: pelagic and benthic. Pelagic fisheries will have an impact on the pelagic component by removing the top predators, but whether they have an impact on the benthic component depends on the degree of bentho-pelagic coupling.

The first analyses that need to be done to examine interactions between seamounts and pelagic fisheries are to establish a reliable map of seamount locations, to characterise the surface oceanography around seamounts using satellite data and to examine fisheries data in relation to seamounts. In situ data then need to be collected to characterise the seamounts in terms of bathymetry, geology and oceanography as well as biological samples from both benthic and pelagic components.

Bertrand Richer de Forges (IRD – Noumea, New Caledonia)

The Western Tropical Pacific is characterised by relatively shallow waters and a high concentration of shallow seamounts, particularly north of Fiji. IRD conducted cruises on seamounts in the Pacific region between 1976 and 2002 under the MUSORTOM project. The south-west Pacific, including the Norfolk ridge and Lord Howe ridge in south of New Caledonia area, were particularly well sampled.

As far as the benthic fauna is concerned, seamounts look very isolated even if they are not very far from each other; in New Caledonia, even over a short distance, more than 50% of the benthic fauna is different on each seamounts and a lot of endemic species are found. A major problem of seamount studies is that the large number of samples collected is often not studied, basically because of the lack of taxonomists.

During the more recent MUSORTOM cruises, the shape of the studied seamounts was determined using a 3D echosounder onboard the RV Alis. Seamounts from the Norfolk ridge are older than hot spot seamounts such as the MacDonald seamount.

Differences in diversity were observed between French Polynesia (BENTHAUS cruises) and New Caledonia, with more diversity in the latter. With the help of a large number of taxonomists, new species have been described and extinct species rediscovered.

Jock Young (CSIRO – Hobart, Tasmania, Australia)

As part of a larger study examining the ecosystem dynamics of the Eastern Tuna and Billfish Fishery (ETBF) off eastern Australia a deepwater seamount located at 26°S, 158°E was observed in relation to the regional physical and biological oceanography over a two week period in September 2004. The seamount was contrasted with two separate study areas, one near the continental slope and another in open ocean waters to the east of Australia. The distribution, abundance and diversity of primary productivity, zooplankton, micronekton and large fish predators were compared between the three sites using an array of equipment and procedures. These included comprehensive hydrographic observations using a CTD, multiple opening-closing nets to sample discreet depths for plankton and micronekton, acoustics to examine the DSL and a longliner to catch and electronically tag large tuna and billfish. In summary, we found the DSL was pierced by the seamount, which rose to 485 m below the surface. We did not detect any increase in primary production over the seamount. However, at the edges of the seamount at depths between 600 and 400 m there was higher acoustic backscatter corresponding to concentrations of deepwater fishes (mainly family Myctophidae) and crustacea. The relative biomass of these concentrations was not significantly different from the surrounding waters, although this may reflect the difficulty of sampling in close proximity to the seamount edge. Over the seamount the water column was characterized by a lack of acoustic scatter. The results of larger fish (tunas and billfish) electronically tagged over the seamount are yet to be analysed but preliminary analyses showed different vertical distributions of swordfish tagged on and off the seamount.

David Itano, (PFRP, University of Hawaii) (cf. Annex 3 *for complete abstract)*

The central Pacific region is rich in seamounts due to the active volcanic hotspot that created the Hawaiian Islands and the Emperor Seamounts. The Emperor seamounts have been the subject of fisheries by foreign trawlers since 1969, and by the Japanese for albacore (longline since 1938 and pole-and-line since ~1973) and they are known to aggregate bluefin tuna. Information on the biology and fisheries of the Hawaii and Emperor seamounts was documented during the 1984 Shimizu Seamount Workshop. Other seamount fields exist to the north (Musicians) and south (Navigator) of the Hawaiian Islands. Those two fields are targeted by Hawaii-based tuna and swordfish longliners including the Cross Seamount which rises to 330 meters depth, and aggregates dense schools of juvenile bigeye and yellowfin. This has lead to the formation of a fishery since ~ 1976, landing 80% of bigeye and 20% of yellowfin of 15 – 30 kgs. This fishery targets low value juvenile fish, which has caused conflicts with other pelagic fisheries. In response the PFRP has funded studies on the Cross Seamount, in particular the Hawaii Tuna Tagging Project, to investigate residence times, exploitation rates and movement of tunas. Over 72% of tag releases and recaptures were taken on seamounts, highlighting their importance to the aggregation and vulnerability of tuna. Gut content analyses of tuna showed differences in feeding behaviour: bigeye feeding successfully on a broad range of mesopelagic species, yellowfin feeding poorly on smaller amounts of epipelagic preys. It was suggested that seamounts be classified into categories of: (1) physical / bathymetric and structural; (2) physical / oceanographic; and (3) biotic elements. The author suggested that important criteria in relation to pelagic species include: the vertical behavior of the associated species; the depth and structure of the seamount above ~500 meters; the vertical temperature and productivity profiles around the seamount; the characteristics of the mesopelagic boundary community and prey organisms; and the characteristics of horizontal and vertical water movement.

Bruno Leroy, (SPC – Noumea, New Caledonia)

The Papua New Guinea (PNG) tagging project will constitute Phase 1 of a full regional campaign; this project is designed to assist PNG to manage its tuna fishery and to improve the understanding of the pelagic ecosystem in the Western and Central Pacific Ocean. A new basin-scale tagging project has been highlighted as a research priority by successive meetings of the Standing Committee on Tuna and Billfish and by the Scientific Committee of the Western and Central Pacific Fisheries Commission.

The six months of field work should start in late mid-2006 in the waters of PNG, mainly in the Bismarck Sea and adjacent areas. A pole-and-line vessel will be used as the tagging platform.

It is planned to conventionally tag 30,000 tunas from the 3 main commercial species (bigeye, skipjack, yellowfin) to obtain information on their stock dynamics and their local exploitation rates. Archival and sonic tags will be also deployed on these species to obtain information on the dynamics of tuna associations with Fish Aggregating Devices (FADs), in particular residence times, vertical and horizontal movements and FAD interactions. Some FADs as well as some selected seamounts will be equipped with listening stations able to record the presence of tagged fish.

Biological sampling will be undertaken during the tagging project; however, due to its specialisation, the vessel used will have limited possibilities for recording oceanographic or acoustic data, plankton and epipelagic prey samples. Nevertheless, fish samples (stomach contents etc.) will be collected routinely. Particulate Organic Matter sampling and vertical sea water temperature/depth profiles may also be collected.

Alex Rogers, (IOZ – London, United Kingdom) (cf. Annex 3 *for complete abstract)*

Seamounts are raised areas of topography on the seabed with a limited extent at the summit. Mapping studies have indicated that there maybe as many as 100,000 seamounts in the world’s oceans with an elevation of more than 1000m, with the majority of these in the Pacific. Seamounts have become a hot topic in marine science because they have been found to host diverse communities of benthic organisms, with a high degree of endemism and specialist deep-sea demersal fish species, and they also attract pelagic fish species.

IUCN and DOQ are collaborating on the GEF-OFM project to investigate seamounts in the vicinity of Fiji, Tonga and Samoa in 2007 in a series of 4 cruises. The vessel provided by DOQ, the RV Alucia is equipped with multibeam sonar and two submersibles, for investigation of biological communities to a depth of 1000m. In addition, CENSEAM will also provide support for the project through organisation of science and provision of additional sampling equipment for the planned cruises.

A sampling programme was outlined with the aim of standardising sampling operations for seamounts. The protocol entailed a series of oceanographic, geophysical, shallow and deep surveys of benthic communities and studies on the pelagic ecosystems. The sampling strategies were discussed, and suggestions were made to enhance the sampling programme through collection and acoustic tagging of large pelagic and demersal fish species. In addition, the cruise tracks were modified to incorporate seamounts of interest to pelagic fisheries and to reduce the number of sites investigated to allow for more sampling on fewer seamounts. The cruises may also be supplemented by involvement of research or fishing vessels for the purposes of enhancement of studies of pelagic and demersal fish.

3. Discussion

Some particular issues arising during the presentations were discussed at the time, and a general discussion was conducted after the presentations mainly during the second day of the meeting. The different subjects discussed are detailed in this chapter grouped according by topic and not necessarily by the order in which they were discussed.

3.1. Seamount definition and classification

There is a growing consensus in the scientific community to define a seamount as an isolated underwater feature of limited extent across the summit usually composed of hard substrate and with an elevation higher than 1000m above the seafloor.

However, experience has shown that any elevation can have an impact on the surrounding ecosystem with, for example, very specific fauna observed on a 12m elevation feature in the North Atlantic (Bett, 2001). An operational definition of seamounts appropriate to pelagic fisheries ecology might have to take into consideration underwater features less than 1000m of elevation and of different shapes, such as terraces, ridges, banks, plateaus, etc., which are normally excluded from the formal definition of a seamount but may still be relevant for fisheries.

In regards to the relevance of seamounts to pelagic ecology and fisheries, the summit depth appears to be as important as the elevation. From this point of view, seamounts can be classified into 3 classes (Anon., 2006):

1) Shallow: summit reaching the euphotic zone,
2) Intermediate: summit not reaching the euphotic zone but above the lower limit of the Deep Scattering Layer (DSL), and
3) Deep: summit below the DSL.

Seamounts in Class 1 and 2 are the ones of interest for this study as they may be characterised by specific oceanographic features linked to a more dynamic environment that will have a potential impact on the pelagic ecosystem and fisheries exploiting it.

Atlas data and calculation of the depth of the euphotic zone and of the DSL would help to classify known seamounts into these 3 categories.

3.2. Bathymetry and benthic ecology

3.2.1. Bathymetry and seamount location

The number of potential seamounts in the Pacific Ocean could be around 30,000, but less than 1,000 have been properly identified and (as of 1988) less than 150 had been explored (Smith & Jordan, 1988). There is a crucial need to gather accurate bathymetric data at a very fine scale in a way to properly identify the seamounts.

Bathymetric data for the location of seamounts comes from 2 major sources: satellite-derived data and ship-derived data.

Satellite-derived data (radar altimetric measurement of sea-surface height)

These data provide potential locations of seamounts with global coverage of the oceans. The best available bathymetric dataset is ETOPO2, which is a bathymetric model largely derived from gravity anomalies detected by satellite. Seafloor data between latitudes 64° North and 72° South are from the work of Smith and Sandwell (Smith & Sandwell, 1997). These data were derived from satellite altimetry observations combined with carefully, quality-assured shipboard echo-sounding measurements. However, topographic data on seamounts are available only at the resolution of the underlying satellite data, *i.e.* 2 minutes; *ca.* 4 km.

Kitchingman and Lai (Kitchingman & Lai, 2004)) applied a geometric algorithm to this dataset consistent with the strict, general definition of seamounts to identify the locations of seamounts. Therefore they do not identify as seamounts features rising less than 1000m above the seabed. For the same reason, other underwater features such as banks are not included in this dataset. Some problems have also been identified for the estimation of the summit depth and some atolls have been misidentified as seamounts.

These datasets constitute a useful working base for the identification of seamounts; however, they do need to be screened and cross-checked to remove false positives and to add otherwise known features of interest that have not been detected.

Ship-derived data (echo-sounders, wide beam, multi beam)

The data obtained from seafloor mapping is generally far more detailed than satellite-derived data but due to the expense of at-sea sampling it covers more limited areas. These data are essential firstly to validate the locations of seamounts and then to provide high resolution maps of the topography of the seamounts. Mapping is important to determine if any underwater feature is hazardous to navigation, but also to plan submersible survey and benthic sample collection. Depending on their depth and size, mapping of seamounts with a multibeam echosounder can take from 2 days to 1 week.

Seamount locations as well as detailed bathymetric data are available for New Caledonia, New Zealand and Australia. Bathymetric data collected in French Polynesia (Austral Islands) and in Pacific equatorial areas should be reasonably easy to access. It is highly probable that Hawaii and Japan also have good bathymetric datasets. The South Pacific Applied Geoscience Commission (SOPAC) should hold data for the region but previous correspondence to obtain complete datasets was not successful.

Mapping of New Caledonia seamounts has been carried out since 2002 from the RV Alis using a 3D echosounder. More recent geology cruises have been conducted for the delimitation of the EEZ but bathymetric data are still confidential and not accessible. Off eastern Australia, detailed information is available for a number of seamounts in the region. Data on these seamounts is held by CSIRO Marine and Atmospheric Research and by Geoscience Australia. Bathymetric data from French Polynesia should be available through Alain Bonneville from the Institut de Physique du Globe in Paris. Detailed data for the equatorial Pacific were collected by the French RV Atalante.

These collections could constitute a first validated set of bathymetric data to help determine the impact of seamounts on pelagic ecosystems and fisheries.

For some areas, only admiralty charts are available, which are of variable quality, being derived for some areas with much detail and for others with much less. There is also some published work that may provide some local information on bathymetry, *e.g.* geological studies conducted by Hart *et al.* (Hart *et al.*, 2004) in Western Samoa.

3.2.2. Benthic ecology

The description of benthic fauna and its diversity was mentioned as a possible way to characterise seamounts in conjunction with bathymetry, geology and oceanography. Biodiversity of benthic organisms has been explored on several seamounts in the Pacific, *e.g.* IRD conducted an inventory of benthic fauna during the MUSORTOM cruises in Tonga Kermadec, Lord Howe Ridge, Fiji, New Caledonia, French Polynesia – Australes, Solomon Islands. Results are published in "Tropical Deep Sea Benthos" series by *Publications Scientifiques du Museum* in the collection *Memoires du Museum National d'Histoire Naturelle* (http://www.mnhn.fr/musorstom/).

From information collected from previous exploratory cruises, benthic fauna on seamounts appears to be characterised by a very high percentage of organisms previously unknown to science: 54% of the species collected during the 2002 IRD cruises were new. The high number of undescribed species makes it difficult to compare the biodiversity of different seamounts or of continental slope and seamounts.

Seamounts are different from continental slopes and can be compared to islands as far as faunal biogeography is concerned; this has been demonstrated with corals. Like islands, seamounts appear to be characterised by a high level of endemism and very close seamounts can show very distinct benthic fauna with high degrees of endemism. However, it is recognised that endemism can be a sampling artefact as a very small number of seamounts have been explored. Moreover some species might appear to be endemic when they are actually present on the continental slope but in very low abundance and sometimes not detected. It is actually the species composition at seamounts, such as the absence of some particular predators, that will induce adaptation and even speciation leading to endemism, *e.g.* some seamount mollusca have thinner shells than in shelf communities as their main predator was absent.

Another characteristic of isolated islands was mentioned as a potential effect of isolation of seamounts: gigantism and dwarfism. However, these phenomena have not been studied and no information is presently available on this subject.

Depth zonation of benthic fauna is a very clear pattern, but there is little information on the horizontal distribution of these organisms. The number of seamounts explored is too low to provide explanations on the geographic partitioning of species. Variability is observed (*e.g.* fauna is poorer in the Central Pacific) but the patchiness of samples does not allow for any general biogeographical patterns or trends to be identified.

Sampling benthic fauna

According to the topography of the seamount, the depth of the summit, the nature of the substrate and oceanographic conditions (*e.g.* strong currents on the summit), it can be very challenging to sample benthic fauna. Measuring biodiversity requires working in different areas of the same seamount. Different types of sampling gear have to be used to collect samples of different size ranges and mobility: high-resolution video for large mobile specimens, submersible manipulators and suction samplers, epibenthic sleds and beam trawls for megafauna, fish or crustacean traps, baiting stations to attract fauna, etc. Because of the high degree of endemism and undescribed species, the specimens need to be photographed fresh immediately after collection, before being stored into a fixative and sent to taxonomists for identification and description.

Quantitative sampling for biomass estimates is difficult and it is more realistic to hope to obtain semi-quantitative measurements by comparison of the quantities collected in the different tows. Huge variability is expected if different areas of the seamount are sampled. Video or scuba transects are suitable to estimate percentage of coverage and trawls can provide semi-quantitative estimates of biomass.

A large number of different studies can be envisaged on the specimens collected, including genetic analysis for phyllogenetics, molecular bar coding, isotope analysis for trophic relationships and for paleogeographic studies using sponge spicules or gorgonians to investigate climate change. It has been noticed that the slow growth and high longevity (up to 400 yrs) of some organisms make them good recorders of ENSO variability, which relates directly to pelagic fisheries.

It is important to realise that heavy sampling gear is needed to work on seamounts with rough bottoms and that the nets used are quite susceptible to damage. Deeper seamounts may increase the vulnerability of sampling gear in this respect.

3.3. *Pelagic ecology and oceanography*

3.3.1. Scale of influence of the seamounts on the pelagic ecosystem

It is expected that class 1 and 2-seamounts as defined in the paragraph 3.1 *Seamount definition and classification* (page 13) (respectively reaching the euphotic zone and the lowest level of the DSL) are the features that will have some influence on the pelagic part of the ecosystem.

If the vertical scale of influence seems well defined, the horizontal impact of the seamounts on the pelagic ecosystem is unclear. For example, Horizon seamount study showed that it had an influence on pelagics up to 100 kms away. The horizontal scale of influence depends on many factors including oceanographic parameters around the seamounts but a distance of 50 kms away from the seamount may be a reasonable expectation and a good compromise.

Different methods were mentioned to try and establish the distance of impact of seamounts on pelagic ecosystems:

- interviews of fishermen fishing around seamounts and an examination of time-series of catch and effort data,
- analyse remote-sensing data to detect particular oceanographic and biological signals such as currents, upwelling, primary production, distribution of phytoplankton that could be impacted by the presence of the seamounts. However it was noticed that the subsurface effects won't be detected using remote-sensing data,
- conduct sampling around one or two chosen seamounts with a rectangular sampling grid; such sampling is important but requires a lot of resources and an entire scientific cruise would be necessary to cover the subject,
- analyses of gut contents of organisms on and near a seamount to investigate trophic links.

According to oceanographic conditions around the seamounts, plankton can be expected to drift away inducing aggregations of fish away from the seamount but still linked to it. Previous studies showed that vertical distribution of DSL is perturbed on the slopes of the seamount but the DSL signal comes back to normal very quickly when the distance to the seamount increases (Koslow, 1997; Young *et al.*, 2004).

Sampling of pelagic organisms at different distances from the seamounts could be necessary to confirm the scale of influence of the seamounts, however it could be difficult and a simplified procedure of sampling on/off the seamount could be an acceptable compromise.

3.3.2. Why do seamounts attract pelagic fish?

A commonly stated hypothesis to explain the aggregation of pelagic fish around seamounts is enhanced primary productivity due to particular oceanographic conditions supporting a rich ecosystem. This enhanced primary productivity would require that the top of the seamount penetrates the mixed layer and not just the DSL depth, and that the injection of nutrients at the surface stays for sufficient time for plankton to develop. However, it was noted that it is not only the top of the seamount that is important but the whole area, and its influence on water flow over and around the seamount.

In many observed seamounts there is no enhanced productivity detected. Actually, the presence of strong currents above the summit of the seamounts makes it difficult to measure the productivity. The high productivity hypothesis is therefore not proven and a newly developing idea is that the DSL is trapped by seamounts and will act as the feeding source attracting the predators.

The importance of DSL to the aggregation of fishery resources over seamounts has been suggested by studies in Hawaii. Results from tagging studies indicate that bigeye tuna tend to remain seamount-associated twice as long as yellowfin. Comparative gut analyses of bigeye and yellowfin tuna caught in concurrent seamount aggregation indicate that the bigeye tuna were feeding very successfully on a wide mix of mesopelagic organisms (Grubbs *et al.*, 2002). Yellowfin caught from the same time/area strata were found to be feeding poorly on epipelagic organisms.

A feeding role is not the only function of seamounts for pelagic fish. They probably have different roles for different life-history stages of some species: spawning grounds, feeding grounds, and nursery areas.

Environmental variability must be considered regarding the different roles of seamounts in the life history of pelagic species. Interannual variability such as ENSO as well as seasonal events such as large wind reversals or monsoonal winds will be relevant for life history parameters (*e.g.* spawning period) of pelagic species. Seasonality probably has a stronger impact in temperate areas than in equatorial areas, as already observed in yellowfin tuna, for which spawning seasonality varies according to latitude (Itano, 2000).

3.3.3. Oceanography around seamounts

By disrupting water flows and creating perturbations such as advection and dispersion, seamounts coming up to ½ of the water column will have an impact on the overlying ocean, inducing various effects on currents and potentially on isotherm distribution.

These phenomena can develop at different scales: at a large scale it was mentioned that the seamount chain located off the east coast of Australia may constrain the East Australia Current before it moves east (Young *et al.*, 2004); at a more local scale, current shearing, eddies and Taylor columns can form in the vicinity of seamounts.

These perturbations in oceanographic variables at sub-mesoscales may allow the categorisation of seamounts using dynamic environmental properties. Oceanographic features can also be detected through signals in phytoplankton and zooplankton.

Remote sensing (*e.g.* ocean colour) could be a very useful tool to detect such features in oceanographic variables. This could also help in choosing sites of interest to focus field work and in determining the scale and directions with which to sample. It is important to keep in mind that some of the more subtle effects due to seamounts are lost in larger scale phenomenon such as mixing of tropical/subtropical waters.

3.3.4. Primary production

At the ocean basin scale, primary production can be examined and monitored using remote sensing data of ocean colour. *In situ* calibration of ocean colour with fluorometer measurements and estimates of production with incubation is possible but this type of calibration is laborious and very specialized.

3.3.5. Plankton and micronekton

Historical work has been done on mesopelagic, and planktonic organisms by IRD (Grandperrin, Claude Roger, Repellin, Geredra) in the 1970's, but no recent work has been conducted by this institution in the Pacific.

Acoustic work (including ground truthing with Fat Buoys and nets) recently conducted by CSIRO with a 38 kHz sounder identified that the Deep Scattering Layer (DSL) included two layers at night (1 layer that vertically migrates upwards and one that does not) and showed a very good correlation between the acoustic values and the biomass of the catch with the nets (Young *et al.*, 2004). This study carried out in Eastern Australian waters demonstrated a lot of variability within the regions but no clear differences. For the upper layer, no differences are obvious in the different areas explored (inshore, offshore) except at the depth level of the seamount summit, where there is a gap in biomass immediately above the seamount and evident concentration around the surface edges and sides; however, it is difficult to sample correctly at the level of the summit because of the strong currents. There is a difference in the vertical distribution but not actually in the biomass.

The DSL distribution at the vicinity of the seamounts seems to vary with observations. In some cases there is no DSL on the seamount itself while it is still present on the edges; in other cases the DSL is carried over the summit.

A previous CSIRO study comparing the biomass and species composition of micronekton inside and outside warm-core eddies off eastern Australia showed only subtle differences between the two environments even though the eddies were derived from tropical-origin Coral Sea water (*e.g.* (Brandt, 1981; Griffiths & Wadley, 1986)). It appears that in order to detect any differences in the distribution and species composition of the pelagic component (micronekton particularly but also plankton – see (Young, 1989)) very contrasting situations have to be compared. The pelagic component of seamount ecosystems presumably presents more similarities with latitudes than the benthic component, partly due to respective low and high diversity; extreme situations at large spatial scale therefore have to be compared to actually detect some differences into the pelagic component. A tropical versus temperate approach was suggested to try and detect differences in the biomass, distribution and species composition of the DSL around seamounts. This tropical/temperate comparison would be of great interest from the pelagic fisheries point of view as tropical waters are dominated by skipjack and yellowfin tuna and temperate areas by albacore tuna.

It was noted that it is difficult to find skilled personnel for zooplankton identification and study. However, to identify some differences between areas of important contrast, examination of broader functional groups could be enough, which would not require species identification. For micronekton, there are more specialists involved.

3.3.6. Large pelagics

Seamounts are known for aggregating large pelagics but little is known about their movements around seamounts. Previous studies have shown that seamounts can have different effects according to the species. Tagging studies have shown in terms of residency that bigeye remain associated with seamounts twice as long compared to yellowfin (Holland *et al.*, 1999; Adam *et al.*, 2003). Also, bigeye have a shallower behaviour when around the seamounts (Musyl *et al.*, 2003) Toby Patterson CSIRO unpublished data). Seamounts affect the vertical behaviour of the fish, but it is more difficult to have an idea on the effect on the fish horizontal distribution. It has been suggested that, as has been observed in the Coral Sea, some tuna could be resident and some migratory, thereby showing variation in behaviour around the seamounts. Feeding is probably the main reason why large pelagics gather around seamounts.

One example was mentioned of acoustic tags associated with a listening station operating on the top of a seamount in the Sea of Cortez to monitor yellowfin, sharks and the movements of other pelagics (Klimley *et al.*, 2003). Sonic tracking does not seem to be very suitable as it is very labour intensive and time consuming, so the fish can usually only be followed for up to 3 days. Acoustic tags and receivers therefore seem more appropriate for long-term monitoring of pelagic residency and behaviour. The use of depth sensing acoustic tags also allow the collection of fine scale diurnal vertical behaviour of fish in association with seamounts.

Different projects are under development to try and address this topic: CSIRO is implementing a project to study the fidelity of large pelagics including swordfish around seamounts using pop-up satellite archival tags[1]. A tagging programme is also being developed by SPC to monitor the movements of tuna around FADs and seamounts in Papua New Guinea.

To better understand the impact of seamounts on the aggregation of large pelagics, it is obviously important to obtain biomass estimates around seamounts. For this purpose, acoustic work as carried out during the ECOTAP programme in French Polynesia (Anon., 1999; Bertrand *et al.*, 2003), or listening stations as developed in the FADIO project (http://www.fadio.ird.fr/), could be very useful. Acoustic work needs different equipment in order to detect different species groups (*i.e.* large or small pelagics) and ground truthing is important to validate the data. Appropriate equipement properly set up can potentially provide information on density, species and size.

Alongside the monitoring of movements and biomass on seamounts, studies of trophic interactions could help explain the link between seamounts and large pelagics using stomach contents analysis as well as fatty acid, stable isotopes and RNA:DNA ratio. Diet studies of tuna around seamounts have already been conducted in Hawaii (Grubbs *et al.*, 2002).

The presence of large pelagics is also linked to oceanographic conditions. The relative influence of localised seamounts and larger scale oceanographic conditions, such as water masses and SOI, was also discussed. SOI effects are more important closer to the equator so the relative importance of seamount and SOI effects could vary according to the latitude. It was suggested that subtropical/tropical seamounts may not have the same impact as temperate seamounts on the aggregation of large pelagics.

To identify how seamounts relate to large pelagics and which factors are important to resident fish around seamounts, it seems important to have a mechanistic approach by conducting ecological studies on feeding, movements, biomass and oceanography.

[1] Wilcox, C. (2006). Investigation of local movement and regional migration behaviour of broadbill swordfish targeted by the Eastern Tuna and Billfish Fishery. AFMA project.

3.4. Bentho-pelagic coupling

The description of benthic fauna is one way to characterise seamounts, along with topography, oceanography, geology and other variables. However, for the purpose of determining the impact of the pelagic fisheries on the seamount ecosystem it is important to try and elucidate if there is a link between benthic and pelagic components of the seamount ecosystem. Bentho-pelagic coupling is not a new idea but seamounts present a special case with particularly difficult sampling conditions.

Several potential links have been discussed during the workshop:

1. trophic link,
2. ontogenetic link and
3. mechanistic link.

It seems that bentho-pelagic species both feed on pelagic preys (micronekton, DSL) such as shown for the alfonsino (*Beryx sp.*) in New Caledonia (Lehodey, 1994) and benthic preys. A direct trophic link exists between bentho-pelagic species and seamount benthos (Parin *et al.*, 1997).

For the pelagic species the trophic link with the benthos is much less obvious. It is believed that large pelagics (tunas…) rely mainly on the pelagic, planktonic and DSL organisms to feed and they would not feed directly on the benthic species. Food web modelling on some seamounts off East Tasmania showed there was little link between pelagic and benthic component (Bulman *et al.*, 2002). No example could be cited of pelagic species feeding directly on benthos (Grubbs *et al.*, 2002) but it was mentioned that they could feed on the predators of the preys attached to the seamounts or on bentho-pelagic species, the trophic link between pelagic and benthic components probably exists but it would not be direct.

To clarify if a direct or indirect trophic link exists between pelagic species and benthos, several techniques could be used such as stomach content analysis, stable isotopes analysis and fatty acids analysis of the different components of the ecosystem. It might also be suitable to investigate the link with the bentho-pelagic component of the ecosystem.

Another link between the pelagic and benthic components is the fact that most of the benthic species are pelagic at some stage (usually as juveniles). The armorhead (*Pseudopentaceros wheeleri*) is a good example of this ontogenetic link between pelagic and benthic components: this benthic species is suspected to have an extended pelagic existence (1.5 to 2.5 years) before recruiting to the seamounts (Boehlert & Sasaki, 1988).

The last possible bentho-pelagic link discussed during the workshop is the mechanistic link. If the seamount habitat offers good conditions for the benthos to develop, then these conditions might also be good for the pelagic component; even if there is no direct link between the 2 components, they are both present for the same reasons (*e.g.* rich environment).

Links between pelagic and benthic components of seamount ecosystems probably exist but they have not been properly demonstrated yet and they are likely to be weak.

3.5. Pelagic fisheries and their relation to seamounts

Several examples of fisheries operating around seamounts were mentioned. In 1996-1997 a swordfish longline fishery in eastern Australia started targeting seamounts (Campbell & Hobday, 2003). In the Hawaiian archipelago, several deep seamounts are targeted by longline fishermen: the Musicians seamounts, and the Navigator seamounts. The intermediate depth Cross seamount (330m depth) has become the fishing grounds for a specific handline and deep longline fishery for bigeye tuna and pomphrets (Bramidae) (Beverly *et al.*, 2004; Itano & Holland, 2000). The Emperor Seamount chain has been exploited by many fisheries, with Japanese longlining started as soon as 1938 and pole-and-line in 1973 mainly for albacore but also bluefin tuna (Yasui, 1986). The Capricorn Seamount (200 m depth) in Tonga is another well known example of a longline fishery targetting a seamount . There is only one known example of a purse seine fishery targeting a seamount: the "Coco de mer" seamount in the Indian Ocean. Two support vessels are actually anchored on top of the seamount to reserve the fishing location for purse seiners of the same fishing companies.

According to oceanographic conditions around the seamounts, the setting of fishing gear will be upstream or else downstream, in the generated eddies and fronts. In some cases short longlines are set, which then drift over the top of the seamount (*e.g.* at Cross Seamount to catch large bigeye (Beverly *et al.*, 2004)). Seamounts will induce stratification of the water column different from the open ocean, impacting on vertical behaviour of the longline. Interviewing fishermen could provide valuable information regards setting on seamounts.

There is a general belief that seamounts attract pelagic species and therefore that fishing should be better around seamounts. However, the effect of the seamounts on the CPUE can be difficult to detect as there are so many factors influencing the CPUE. For example in the work done by Campbell and Hobday (Campbell & Hobday, 2003), they could not show any seamount effect on the swordfish fishery but it is believed that because the depletion of swordfish at the seamount happened so quickly the seamount effect was probably masked by long-term trends in the dataset. Similarly Lehodey *et al.* (Lehodey *et al.*, 1997) and Lehodey (Lehodey, 2001) showed a strong correlation between CPUE and oceanographic features, so in these conditions it would be difficult to detect any impact of the seamounts on the CPUE without relating the presence of the seamount to changes in oceanographic conditions The hypothesis that effects of seamounts on catch data could be more obvious in the temperate areas than in equatorial region could be tested. There is a need for process studies looking at the reasons why seamounts have a positive effect on CPUE.

Studying catch data in relation to seamount positions will pose some problems, mainly because of the quality of the fisheries data. For example, position of purse-seine sets is accurate while the position of longline sets is only approximate, due to the gear (the line can easily reach 100km long) and the fishing strategy (the line drifts for several hours); data will be provided for retained catch only except for observer trip that provides bycatch data but which coverage is low. Also, the mapping of CPUE needs to take into account the closed areas. It was mentioned that ANOVA-type analysis should pull out true/false effect of seamounts on CPUE by species.

The rapid and dramatic depletion of resident swordfish in longline fishery around seamounts off eastern Australia and the fact that no swordfish have been caught on the Brittania seamount for some years now (Campbell & Hobday, 2003) is an example of the impact of pelagic fisheries on the pelagic component of the seamount ecosystem. Little impact is expected from the pelagic fisheries on the benthos because of the presumably weak bentho–pelagic coupling (Bulman *et al.*, 2002); however, it has been acknowledged that large-scale removal of pelagic species will induce a change in the pelagic community that might have, at long term, an impact on the benthic community.

It is not within the scope of this project to study the impact of deep sea bottom trawling (*e.g.* for alfonsino). In any case, although several attempts were made in New Caledonia (last prospecting trip in 2002), these proved to be unsuccessful and there are no such fisheries known in Pacific Island countries and territories. However, it might be necessary to take into account the impact of the benthic drop-line fisheries for deep snappers that have developed in several Pacific Islands (*e.g.* Tonga, New Caledonia). To show any fisheries impact on the seamount it is important that all the fisheries operating are identified, in order to be able to differentiate between the impacts of the different fisheries.

Also, as mentioned in Section 3.4 (Bentho-pelagic coupling), bentho-pelagic species such as those caught by the drop lines might be the link between pelagic and benthic components. In this case the pelagic fisheries could have a direct impact on the bentho-pelagic component and an indirect impact on the benthic component via the trophic link.

Fisheries data for these deep fisheries are not collected by SPC but could be available at the national level (*e.g.* Tonga fisheries has detailed VMS data on deep snapper fisheries); these might have to be considered for the fisheries impact analysis on seamounts.

4. Implementation of seamount research

4.1.1. Analysis of existing data sets

The only reliable, publicly available maps of seafloor bathymetry for large ocean regions derive from satellite-based sensors recording gravity anomalies. The best available dataset (ETOPO2) has a resolution of 2 minutes (2/60^{ths} of a degree; 4 km at the Equator). Geometric algorithms may be applied to this data to identify features of interest, *e.g.* seamounts. This was carried out by Kitchingman and Lai (2004), who identified 14 000 seamounts in the global ocean. However, they applied quite a strict defininition of a seamount and assumed that it should have a rise of 1000 m or more from the seabed and should be roughly circular or elliptical in shape. In reality, much smaller features can also have unique fauna and submerged banks without such a circular shape may also be important for fisheries. The ETOPO2 data also calculates depth relative to a reference ellipsoid, not to mean sea level, and therefore it may fail to detect low-lying atolls and islands as being above sea level. Our first task therefore is to reanalyse this dataset to remove any false identifications of seamounts and to identify submarine banks relevant to fisheries. The OFM project could consider appointing Kitchingman and Lai to produce more accurate data on the position of the seamounts, as has been done by Greg Stone to conduct a fine-scale analysis of Kiribati (Phoenix Islands). Another possibility would be to rewrite the algorithms ourselves and apply them to the original ETOPO2 data.

The OFP maintains a database of pelagic fisheries catch and effort data going back 50 years. This data has been provided by SPC members and by distant water fishing nations and is compiled at a resolution of 1 degree square. In addition we have data from on-board observers for a small percentage of the fleet. This data is on a much finer scale and includes the species composition of bycatch. Our next task is to analyse these data with reference to seamount locations to see if there is any apparent connection between fisheries data (catch-per-unit-effort, species composition, size of fish caught) and seamount presence/absence or other characteristics. Datasets from previous large-scale tagging programs will also be reanalysed to investigate whether there is any obvious site fidelity for fish tagged in the vicinity of seamounts.

As discussed in Section 3.3 (Pelagic ecology and oceanography, page 17), there is a need to investigate the effect of seamounts on the surrounding waters at scales of up to several hundred kilometers. This is because mesoscale eddies may be generated by land masses such as islands and seamounts and there can be downstream increases in productivity, generating favourable habitat for large pelagics such as tunas. Again, the only way to analyse a large area of ocean is to look at satellite data, in this case at sea-surface temperature and ocean colour, which relates to phytoplankton concentration and biological productivity in general. Sea-surface height can also be used to infer geostrophic currents. The combination of data types will allow us to identify those seamounts that have an obvious impact on the pelagic ecosystem.

4.1.2. Sampling strategy for acquisition of new field data

4.1.2.1. General strategy

In addition to the analysis of existing data, new field work will be undertaken during the OFM Project to enhance our understanding of seamount ecosystems in relation to pelagic fisheries. However, chartering boats is expensive and the explored seamounts will therefore have to be carefully targeted.

There are two potential sampling approaches: cruises could explore a large number of seamounts to obtain a descriptive overview of the variability of seamount ecosystems; alternatively, a smaller number of seamounts could be heavily sampled to obtain a more mechanistic understanding of the functioning of the ecosystem in an area of particular interest, *e.g.* to fisheries. A combination of these approaches, with a descriptive phase to select seamounts for subsequent, more detailed study, may be the best solution. In any case, it will be important to keep some flexibility during the sampling programme to allow time to be spent sampling unexpected features of interest.

Seeing as the objectives of the seamount ecology component of the OFM project are to establish the impact of seamounts on pelagic fisheries and the impact of pelagic fisheries on seamounts, a comparative approach seems suitable. Comparison between historically exploited and recently or non-exploited areas would allow the detection of fishing impacts on seamounts. Finding non-exploited seamounts could be challenging but areas that have not been heavily targeted for longline fishing exist in Papua New Guinea. The Wallis & Futuna area is also a good example of a non-exploited area, with many seamounts in its EEZ. By contrast, the Capricorn seamount in the Tonga EEZ has a long history of productive fishing, as does as the Cross Seamount in Hawaii.

Comparison of equatorial, tropical and temperate seamounts could help in detecting and explaining the impact of seamounts on pelagic ecosystems and fisheries. Because of differences in the phenomena driving productivity, it is expected that the impact of seamounts on pelagic fisheries is less obvious in equatorial areas than in temperate areas, where the fisheries target different species, *i.e.* skipjack/yellowfin *vs.* albacore respectively. The study of contrasting environments should help in detecting differences. Brittania Seamount in Australia could be a good case study for sub-tropical/temperate seamounts while the Fiji area would provide data on tropical seamounts and PNG or the FSM/Marshalls/Kiribati area would allow the exploration of equatorial seamounts.

Two sampling programs are under development in the first part of the OFM project. The Tui Delai Gau IUCN/DOQ cruise* is dedicated to the study of seamounts and would cover the Fiji/Tonga/Wallis & Futuna/Tuvalu area, including the exploited Capricorn Seamount in Tonga and some non-exploited seamounts in Wallis & Futuna. The PNG tagging project* will focus on the PNG Bismarck Sea/Solomon Seas and adjacent areas, and should also visit some seamounts. Another area potentially of interest to this project is the heavily fished FSM/Marshalls/Kiribati region. Results of an exploratory cruise organised by Greg Stone (New England Aquarium) with the RV Alucia in late 2006 should provide information on interesting seamounts that may be considered for further studies.

The Tui Delai Gau cruise is planned for January to April 2007*. While no precise time schedule is yet provided for the PNG Tagging project, it should start in late 2006 and continue into 2007. The timing of research cruises will be constrained by the

* Details of cruise plans in paragraph 4.1.3.1, page 30.

availability of suitable boats. For comparative studies, inter-annual variability (*i.e.* ENSO) or seasonality (*i.e.* wind reversals) could also be an issue, especially for pelagic ecosystems. Ideally, to detect seasonal variations, sampling should be repeated on the same area at different times of the year; similarly inter-annual monitoring would require sampling in the same area at the same season in several years. The cost of sampling will probably prevent us from doing such comprehensive sampling, but seeing as this is a 5-year project, it may well be possible to come back to the same seamount if it is particularly interesting. Associated local longliners would be a lower cost option for sampling large pelagics to try and detect seasonal or inter-annual signals.

When studying ecosystems as complex as seamounts, with many different variables to measure and different types and sizes of organisms to collect, it becomes obvious that no ship will be able to measure/collect all the suitable variables/samples. The two-vessel platform approach has been discussed and appears to be a necessary compromise in order to collect all the information necessary for this project. The use of two vessels would allow a wider range of sampling gear, especially when combining a scientific vessel studying oceanography, small pelagics and the benthos, and a fishing vessel catching large pelagics. Concurrent sampling by both vessels is not crucial and might not even be practical, but it would still be appropriate for the gap between the two cruises does not exceed one month in order to avoid any seasonal bias into the data.

4.1.2.2. Variables to measure

In order to characterize seamounts and both the benthic and pelagic components of their ecosystems, it is necessary to measure and analyse a range of physical and biological variables. The list below presents the different variables that should be determined. As noted above, the complete description of seamounts would require a full range of equipment unlikely to be found on the same boat. From this ideal shopping list, the variables measured during any specific cruise will depend on the available equipment onboard and they might be different according to the seamount considered.

It is important to note that measurements and analysis of all variables require extended collaboration with taxonomists and specialists of the different fields.

Physical variables (cf. Annex 4 **for description of sampling equipment)**:

1. Bathymetry: detailed maps of the seamount need to be acquired before any sampling can be done on the seamounts. These will provide seamount size, contour and topography, depth of the summit and of the surrounding bottom. It requires the use of a multibeam sonar scanner. Experience shows that it can take about 2 days just to map a small seamount; however it really depends on the overall shape and size of the seamount.

2. Isolation: this requires the determination of the distance to other seamounts and to the coast. This is simple to measure from charts and with GPS but it is important to record whether the seamount is likely to be influenced by coastal zones.

3. Substrate: this is determined using echosounder data (reflection characteristics) and observations from submersibles.

4. Age: can be determined by sampling rocks and requires a geologist's expertise.

5. Temperature: sea-surface temperature and temperature vertical profiles can be determined using remote sensing data, Conductivity-temperature-depth probe (CTD) and Expendable Bathythermograph (XBT).

6. Ocean color: remote sensing data will provide this information on a broad scale using global algorithms. Ideally this would be calibrated *in situ*. Full calibration of satellite sensors requires a lot of water sampling and fluorometer and salinometer measurements, as well as laboratory analyses, implying preservation of water samples. However, simple calibration of chlorophyll concentration may be obtained using a fluorometer only.

7. Currents: Acoustic Doppler Current Profilers (ADCP) measure currents at the surface and in the water column and would characterise both the horizontal and vertical movements of the water, potentially allowing areas of upwelling to be identified.

8. Carbonate compensation depth (CCD): is calculated from measurements of carbonate ions, pH, pressure, temperature and salinity.

9. Euphotic depth: this is measured by optical sensors

10. Particulate matter: this is measured using a transmissometer, which indicates visibility.

11. Nutrients: concentrations at the surface and vertical profiles can be measured from water samples obtained with a CTD.

12. Dissolved oxygen: this would require the collection of samples and laboratory analysis.

13. Particulate Organic Matter (POM): this is measured by filtering water samples and laboratory processing.

Biological variables (cf. Annex 4 **for description of sampling equipment)**:

Pelagic component

1. Phytoplankton: phytoplankton species composition can be determined by collection with a 200µm mesh net, along with pigment measurement after filtration of about 20l of water. Measurement of productivity requires incubation onboard; it is an important parameter to determine but is difficult as the boat needs to be steady on the top of the seamount despite strong current. Productivity measurement and species composition determination require a lot of time and resources. However, chlorophyll concentration is a good proxy for phytoplankton biomass and can be measured relatively easily, first by satellite remote sensing (see above) and then by in situ flourescence measurement.

2. Zooplankton: the Continuous Plankton Recorder (CPR) can be towed over long distances behind ships of opportunity. Oblique tows of Bongo nets (500 µm or 333 µm mesh size for copepods) can also be considered, as well as EZ opening-closing net; RMT 8 nets would allow us to combine the sampling of both zooplankton and micronekton. Determination of species composition requires specialised taxonomists, but identification can be limited to main taxa only and can be aggregated by functional group; photography and taxonomy are often sufficient but molecular identification can also be considered. Biomass can be estimated for the main taxa.

3. Micronekton / Deep Scattering Layer (DSL): different complementary gear types will be necessary to determine biomass, species composition (*i.e.* biodiversity), and the spatial distribution of micronekton: for biomass and movement estimates, acoustic sonars such as the ship-mounted EK500 or the towed transferable EK60 can be calibrated for biomass by sampling with IKMT nets, MIDOC nets or RMT 12 / RMT 8 opening-closing nets. These nets will provide samples for biodiversity estimation in addition to samples obtained from the stomachs of large pelagics, which are considered better samplers of large fish and squids than classical nets. Ideally, acoustic and net sampling should be done concurrently but they can be done one after the other so long as sampling avoids dusk and dawn, when DSL moves rapidly vertically. Several replicate tows (5 per area) are required to obtain meaningful data. To improve knowledge of these poorly known organisms and to determine their role in the trophic structure of the pelagic ecosystem, specimens from the nets could be collected for isotope analysis and stomach contents. Acoustic data analysis is specialised and time consuming work and will require the collaboration of an expert to examine the data; for highly quantitative applications and for species identification it can also require biological work on acoustic characteristic of the species detected, *e.g.* swimbladder description

4. Large predators: these include many fish species but also seabirds and marine mammals. Species need to be identified and their relative biomass can be estimated from fisheries data for fish and from sightings for seabirds and marine mammals. Their movements around the seamount can be determined by tagging. A wide range of analysis can be conducted on sampled specimens (10 per size class implying different sampling gears or setting characteristics): size, isotope analysis, stomach content, reproduction studies, tagging. Sampling of large pelagics will be limited to fisheries catch, mainly longline; observation by submersibles is not an option. Vertical longlines from research and support vessels can be used. The use of listening stations and acoustic tagging is a powerful technique to monitor large fish movements. It is also worth remembering that some fish must be sampled destructively in order to obtain biological samples, whereas for tagging studies the fish must be alive. It is therefore not possible to sample all variables of interest from the same individuals. Concurrent tagging and biological sampling in the same time/area around a seamount should provide data representative of the tagged fish.

Benthic component

1. Epibenthic macrofauna: different gear can be used to determine biodiversity and biomass of the benthic component. Observation and collection of samples with a submersible equipped with manipulators will allow determination of the percentage of coverage of benthic organisms, a semi-quantitative biomass estimate given at least 4 vertical transects per seamount. It also allows identification of macrofauna and mobile fauna not sampled by collecting gear. However, to determine biodiversity, visual observation is not sufficient: samples have to be collected. In order to minimize the impact of sampling gear, observations can be conducted first, and collecting gear such as beam trawls, epibenthic sleds and dredges can be used on chosen areas, with several standardized tows per seamount. The use of benthic trawls and dredges is easy on flat seamounts but can be very difficult on pronounced topographic features; gear damage is to be expected. Other gear such as traps could collect fish, amphipods and invertebrates. Strong currents on top of seamounts can induce difficulties in deployment so submersibles might be considered for this. Baiting stations coupled with underwater video equipment could provide valuable survey data for species difficult to trap or capture. Scuba diving will also be used for visual transects and collection of samples on shallow seamounts. Infauna is potentially collectable using grabs or submersible collectors to sample sediment.

A wide range of samples may also be collected to acquire more knowledge on these poorly known organisms. Genetic samples can be collected for molecular barcoding and work on evolution, as well as isotope samples for trophic structure determination. Histological studies can be considered in order to elucidate reproductive patterns. Hard parts of corals, gorgonians and sponges (spicules) offer the potential for conducting studies on climate change.

Due to the high endemism and high percentage of new species when sampling on seamounts, it is unlikely that the plateau of the species accumulation curve is reached even with the deployment of significant sampling effort; biodiversity data obtained will only be partial and very rare species might be missed. For the same reasons, species identification cannot only be conducted onboard. Good photographic pictures of fresh samples will be required before preserving them and sending them to taxonomists.

2. Benthopelagic fish: these might be important in any links between the benthic and the pelagic components of seamounts. Sampling of these fish, with identification of species, relative biomass estimates (*e.g.* from deep snapper fisheries data), and biological sampling (*e.g.* stomach content examination) may be an important part of the seamount studies. Fitting a small support vessel with deepwater snapper fishing gear could provide direct sampling capabilities for benthopelagic fish and their gut contents.

4.1.3. Planned cruises and other potential sampling platforms

4.1.3.1. Cruises planned within the OFM Project

The 'Tui Delai Gau' project – RV Alucia /DOQ-IUCN cruise

The following section is a report of the discussions conducted during the workshop in March 2006. However, in June 2006 due to delays in the refitting of the vessel, this project was put on standby with no certainty that it will be conducted during the duration of the GEF OFM project. We have included this section in the report in the hope that this cruise do eventually happen.

The RV Alucia is a research vessel belonging to a private marine science and filmmaking company called Deep-Ocean Quest (DOQ). The vessel has been made available to IUCN for a 4-month scientific cruise in the vicinity of Fiji from January 2007 to the end of April (equivalent to US$3 millions in-kind donation of ship time). Dr. Alex Rogers, the IUCN scientific advisor for this project, is designing the cruise plan.

Although the cruise is broadly constrained by geographical area, seamounts from Fiji, Tonga, Wallis & Futuna, Samoa, Solomon Islands, and Tuvalu EEZ could be explored. A total number of 37 seamounts were mentioned in the first cruise plan draft although this might need to be reduced to focus on areas of interest. Preliminary analysis of fisheries data in relation to seamounts should identify areas of interest to fisheries. A definitive list of seamounts to be visited needs to be determined and there is some flexibility within the geographical constraint. The first cruise plan draft focussed on the observation and sampling of the benthic component; however, the plan will be revised to also incorporate surveys of the pelagic component of greater relevance to oceanic fisheries.

Measurements of environmental variables and collection of samples will depend on available sampling gear and vessel constraints. RV Alucia is primarily used for deployment of submersibles and cannot be expected to be as sophisticated as an oceanographic research vessel. Onboard equipment is limited, setting of gear can be logistically challenging, and the crew is not trained to operate scientific equipment. Nonetheless, onboard CTD and multibeam sonar will measure bathymetric and hydrological variables. Two submersibles plus scuba diving equipment and trained staff will be used for visual survey of benthic macrofauna for both deep and shallow seamounts. These techniques will minimize the impact on the seamounts and will allow us to select areas for the sampling gear transects. Sampling of benthic macrofauna depends on the provision of sampling gears by researchers and institutions involved; CenSeam and IRD can provide some equipment.

Sampling of the pelagic component might be very limited and RV Alucia does not seem ideal for this purpose. There are no pelagic sampling gears presently onboard and the vessel is limited to the deployment of light gears such as small mid-water plankton nets. Acoustic surveys of micronekton will depend on the availability of appropriate sonar equipment and a specialist to deploy the gear and analyse the data. There is no onboard sonar and the acquisition of towed sonar is under discussion. A NERC equipment grant will be submitted in collaboration with Dr. Andrew Brierley. If this bid is unsuccessful use of the GEF OFM project equipment budget will be considerd. There is no certainty that a mid-water trawl to collect micronekton can be operated using the large winch of RV Alucia; if it is possible, the RMT nets would have to be purchased or hired.

Sampling of large pelagics may be possible from the RV Alucia's 28' skiff, using small vertical longlines for sampling and tagging. It would cost less than US$5k to equip the skiff in this way. A companion longline fishing vessel would also be desirable to sample large pelagics. Fisheries Services from the different countries explored by this cruise will be contacted to investigate the potential availability of fishing vessels; discussions have started with Tonga (See "Chartered Fishing Vessels" paragraph). Many seamounts on the provisional cruise plan are shallow (*i.e.* summit <50m depth) and setting a longline around these features can become problematic and caution will have to be taken; in this particular case short vertical longline could be appropriate. However, if there is a strong downstream influence of the seamount on ocean circulation and productivity at some distance the use of horizontal longlines to sample these areas would not be a problem.

Storage of biological samples still needs to be sorted out as the length of the cruise would prohibit the use of freezers due to insufficient capacity. It is probable that ethanol in large quantities will have to be used, with due regard to the complexities and hazards associated with this.

Scientists who could potentially collaborate on this cruise still have to be identified and contacted through CenSeam or other institutions and meetings. This workshop was a good first step in this regard.

The Papua New Guinea tagging project – SPC-OFP / PNG-NFA project

This is the first phase of a larger Regional Tuna Tagging Project, the objectives of which are to obtain information on movements of tuna, exploitation rates, FAD interactions with tuna movements and trophic status, bycatch species. This work is necessary in order to improve regional tuna stock assessments and to address the major priorities of the Western and Central Pacific Fisheries Commission (WCPFC).

The tagging platform will be a chartered Japanese-style pole-and-line vessel equipped for fishing and tagging with dart, archival, and sonic tags coupled with listening stations. The vessel will operate in the Bismarck Sea, Solomon Seas and adjacent areas for a total duration of 6 months. Tagging will be conducted in the main area of the purse seine fishery around FADs, in open waters and around seamounts. Operations other than tagging will be very limited. Measurements of oceanographic data will be limited to vertical temperature/depth profiles obtained from archival tags, though it may also be possible to deploy XBTs. No mapping will be conducted. Acoustic surveys may be feasible but this would require the provision of equipment (*i.e.* towed EK 60) and expertise. However, ground truthing with macronekton nets is hardly feasible. Plankton sampling with small gear could be possible but requires the provision of the net and some installation onboard. Particulate organic matter can be easily sampled.

Sampling of large pelagics will be limited to tuna, which will be available in large amounts but only small specimens. Biological sampling will be carried out, particularly of stomach contents. Sampling of other species is possible using other fishing gear but this would be time consuming. Listening stations should be deployed on seamounts to monitor tuna movements with sonic tags.

The availability of vessels is still under negotiation and no precise time schedule is provided. It may be possible to link up this tagging cruise with scientific work in the same area in order to measure oceanographic variables, sample plankton, micronekton and benthic organisms. The companion vessels/cruises mentioned to complete this study were RV Alis and a CSIRO cruise organised in this areas (see below).

4.1.3.2. Other cruises and sampling platforms of interest

CSIRO cruise in Papua New Guinea

CSIRO is organizing a scientific cruise in late 2006 – early 2007 in PNG waters to try and detect the impact of gold mining. Operating from a 30m research vessel they are planning to conduct water sampling, plankton and IKTM sampling of micronekton. The vessel also has the capabilities to do open-net tows and benthic sampling using bottom sledges and dredges. No acoustic work is envisaged. Results from this cruise could be a good complement to the PNG tagging project. John Hampton will approach Dave Brewer, the contact person at CSIRO in charge of this cruise, to discuss collaboration.

RV Alis

Belonging to the French Institute of Research for Development (IRD) and based in Noumea, New Caledonia, the RV Alis is a 28m research vessel capable of embarking 11 persons and having 15 days of autonomy. She is fully equipped with a 3D echosounder for mapping, CTD (temperature and current profiles), acoustic sonar, plankton nets, pelagic and mesopelagic nets as well as dredges and beam trawls for benthic sampling. The vessel will conduct a research cruise in Solomon Islands in 2007 and it may be possible to charter this vessel from the Solomons to Papua New Guinea areas to complement the PNG tagging project. A formal proposal to use the vessel will be developed, which will have to be submitted by January 2007 for use of the vessel in 2008.

RV Southern Surveyor

Belonging to CSIRO, Australia, this large research vessel is equipped for oceanographic measurements as well as all sorts of biological and geological sampling; however, large pelagics would not be sampled and a companion longliner would be required to collect them. Chartering this vessel commercially would cost about 30,000AUD/day but it is envisaged that we would apply for a research grant for the use of the boat during the 2008-2009 season. The possibility of carrying out a comparative study between seamount ecology in temperate (Australia) and equatorial areas (highly fished Kiribati/ Marshall/FSM area) has been discussed. Collaboration with Tony Koslow in Australia and the GEF OFM Project manager would be necessary to prepare this proposal.

RV Tangaroa

Belonging to NIWA, New Zealand, this large research vessel is fully equipped for oceanographic measurements as well as all sorts of biological and geological sampling as well as trawl fishing. At a cost of about 30,000NZD/day, the chartering of this vessel could be discussed, especially if co-financing (*e.g.* from NZAID) were available.

RV Alucia

Belonging to Deep-Ocean Quest, the capabilities of this vessel have been presented in a previous paragraph. Before the Tui Delai Gau cruise, an exploratory cruise will be conducted in Kiribati / Phoenix Islands. Greg Stone (New England Aquarium) the coordinator of this cruise in conjunction with Conservation International, will be contacted to establish collaboration and to obtain information on the interest of the seamounts in this area. The possibilities of using this vessel for other cruises have been discussed. After the Tui Delai Gau cruise in the Fiji area for the OFM Project, there might be an opportunity to use the boat for another cruise in Papua New Guinea / Solomon Islands area in 2008, after an unrelated cruise in Australia and before she heads to the Indian Ocean. It would be a good complement to the PNG tagging project. However, it has been decided to wait for the results of the first cruise before considering another one with the same boat.

During the circumnavigation of RV Alucia, French Polynesia waters will probably be visited. Good mapping data are available from this area and this EEZ is part of another European project from which funds could be made available to conduct sampling there.

British Research Vessels

One of the British Research Vessels might operate in the South East Pacific in 2007/8; however, this still has to be confirmed. If the vessel is already in the Pacific it would be easier to apply for a grant to use the vessel in the Western Pacific. Dr. Alex Rogers will seek more information on this possibility.

Chartered fishing vessels

Fishing vessels, particularly longliners, would constitute good companion vessels to collect large pelagics alongside the work on oceanography, benthic sampling and small pelagic sampling conducted by research vessels. It would also be a very good way to involve member countries in the OFM project. Local vessels could also be a good option for monitoring the pelagic resources on the seamounts as they could easily visit the same seamount at different time of the year.

Most of the fisheries services of the countries in the area have fishing boats that could potentially be used. However, private fishing vessels might be preferable with their well-trained crew and more-frequently maintained boats. Boats mentioned include the Manila fisheries service 65m-fishing vessel, the Taiwan Fisheries Research Institute boats, the Flamingo Bay based in Honiara and set up as a research boat, and the Fiji and Samoa fisheries services boats.

The Tonga Ministry of Fisheries longliner FV Takuo could be very useful as a companion vessel to RV Alucia during the Tui Delai Gau cruise while operating in Tonga waters. Contacts have been established to discuss this possibility. It was also mentioned that Wallis & Futuna, a non-exploited area, conducted an exploratory longline trip for tuna fishing in 2005. A second trip will be conducted in 2006 and this could represent a very good opportunity to sample large pelagics on the same seamounts that will be explored during the Tui Delai Gau trip. Wallis & Futuna fisheries authorities will be contacted.

5. Conclusions

By gathering experts of different disciplines related to seamounts and pelagic fisheries and coming from different institutions in the Pacific and Europe, this workshop offered a unique opportunity to establish and strengthen collaboration between the people and the institutions represented at the meeting.

The workshop allowed participants to share their knowledge, their views and to discuss many subjects, such as the definition of seamounts, benthic and pelagic ecology (including bathymetry and oceanography), bentho-pelagic coupling, pelagic fisheries on seamounts, and the implementation of seamount research under the OFM project. In regards to implementation, it was decided that two directions should be explored.

Firstly, existing data will be analysed to try and detect any impact of seamounts on pelagic ecosystems and fisheries. This will require the refinement of the Kitchingman & Lai (2004) seamount dataset to remove false identifications and to cross-check the dataset with seamounts known from other sources of information. Consequently, satellite data will be explored to investigate relationships between seamount locations and sea-surface temperature, height, ocean currents and productivity. Finally, the fisheries data will be analysed by comparison with the seamount locations and remotely sensed data.

Secondly, it is planned to acquire new field data to better understand the interactions between seamounts and fisheries. Comparison of exploited and non-exploited seamounts as well as equatorial, tropical and temperate seamounts was considered to be a good approach to try and detect any impact. A list of variables to measure in order to properly characterise seamounts has been developed; this includes physical variables such as bathymetry and oceanography, and biological variables such as benthos, plankton, micronekton and large pelagics. We would then identify the species, estimate the biomass, monitor the movements and collect samples of species associated with seamounts. Cruise plans and the activities of two projects under development have been discussed to refine the sampling strategy. The need for chartering companion vessels was emphasized to allow the sampling of all the necessary variables: scientific cruises collecting benthic and DSL samples and oceanographic data should be complemented by fishing vessels to collect large pelagics, and conversely, tagging/fishing vessels cruises should ideally be complemented by scientific vessels. Opportunities to charter companion vessels (fishing and scientific vessels) to undertake joint cruises between different institutions were considered.

The outcomes of this workshop were presented at the pre-session of the 5th SPC Heads of Fisheries meeting on the 31st of March 2006 in Noumea, New Caledonia. A partial draft report of the Seamount research planning Workshop comprising the Section 4 (Implementation of seamount research, page 24) was distributed to the participants, and the opportunity to comment on the outcomes of the workshop was given to the delegates of the countries involved in the GEF project. A draft full report will be presented as an Information Paper at the 2nd Regular Session of the Western and Central Pacific Fisheries Commission's Scientific Committee in August 2006 and the Final Report will be presented to the GEF OFM Project Steering Committee meeting in October 2006.

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Annex 1. Summary and partial description of the structure of the GEF-funded Pacific Islands Oceanic Fisheries Management Project (OFM project) (http://www.ffa.int/gef/).

THE GEF PACIFIC ISLANDS OCEANIC FISHERIES MANAGEMENT PROJECT (OFM project)

GOAL

to achieve global environmental benefits by enhanced conservation and management of transboundary oceanic fishery resources in the Pacific Islands region and the protection of the biodiversity of the Western Tropical Pacific Warm Pool Large Marine Ecosystem.

PACIFIC ISLANDS OCEANIC FISHERIES MANAGEMENT

Countries involved

Cook Islands		Federated States of Micronesia		
Kiribati	Marshall Islands		Fiji	Nauru
Niue	Palau	Samoa	Tonga	
Papua New Guinea		Tuvalu	Tokelau	
Solomon Islands		Vanuatu		

Objective 1: Information and Knowledge

to improve understanding of the transboundary oceanic fish resources and related features

Objective 2: Governance

to create new regional institutional arrangements and reform, realign and strengthen national arrangements for conservation and management of transboundary oceanic fisheries resources

Component 1: Scientific assessment and monitoring enhancement

to provide improved scientific information and knowledge on oceanic transboundary fish stocks and their ecosystem, with a particular focus on the ecology of seamounts in relation to pelagic fisheries

- 1.1. Fishery monitoring, coordination and enhancement
- 1.2. Stock assessment
- 1.3. Ecosystem analysis
  - 1.3.1. Dynamics of the pelagic ecosystem with focus on trophic relationships
  - 1.3.2. Ecology of seamount, their impact on aggregation and movement of pelagic species and fisheries impacts thereon
  - 1.3.3. Ecosystem-based scientific advice
  - 1.3.4. Estimates of the levels of by-catch in oceanic fisheries
  - 1.3.5. Results of ecosystem analysis and proposals for long-term ecosystem monitoring

Component 2: Law, policy and institutional reform, realignment and strengthening

to assist Pacific Island States as they participate in the work of the new Western & Central Pacific Fisheries Commission

Annex 2. Agenda and themes of discussion of the seamount research planning workshop circulated before the beginning of the workshop.

Seamount research planning Workshop
20-21 March 2006
Oceanic Fisheries Programme
Secretariat of the Pacific Community
Nouméa, New Caledonia

AGENDA

I suggest we divide the day in roughly 4 sessions of 1h30:

- 8:30-10:00: presentations-discussions
- 10:00-10:30: tea/coffee break
- 10:30-12:00: presentations-discussions
- 12:00-13:30: lunch break
- 13:30-15:00: presentations-discussions
- 15:00-15:30: tea/coffee break
- 15:30-17:00: presentations-discussions

Several speakers are invited to do presentations that will constitute the starting point of the discussions to elaborate the research plan.

My suggestion is to start with a short presentation of the context and expectations for this workshop. Then we will have several speakers who will present work already conducted on seamounts in the region and we should finish by the presentation of the new projects that are already planned but still in preparation/discussion, so now is a good time to modify them if necessary.

There is no formal timing for the presentations as I expect many discussions during and between the talks.

PRESENTATIONS – provisional titles

Valerie Allain
The OFMP and the objectives of the workshop

Bertrand Richer de Forges
Seamounts explored by IRD in the Pacific Ocean

Jock Young
The Southern Surveyor 2004 voyage, pelagic habitat and community comparisons in the fishing grounds of the tuna and billfish fishery off eastern Australia

David Itano
Seamount pelagic fisheries and research around Hawaii

Bruno Leroy
SPC-PNG Regional Tuna Tagging Project

Alex Rogers
IUCN / Deep-Ocean Quest joint study of seamounts in the Central Pacific Ocean.

SOME THOUGHTS AND SOME QUESTIONS TO THINK ABOUT

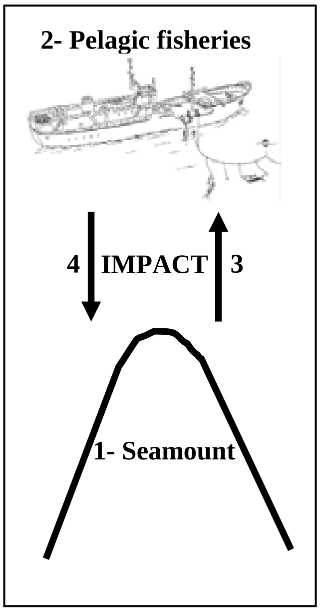
To better understand the ecology of seamounts and to assess the impact of seamounts on the pelagic fisheries and the impact of the fisheries of the seamounts, we might consider to:

1- characterize the seamounts (biological and non-biological parameters) – there are very few data for this part of the study and that's where most of the sampling and work needs to be done

2- characterize the pelagic ecosystem and fisheries (CPUE, species composition of the catch, size of the catch, movement of the fish, trophic structure) – fisheries data are collected by SPC (CPUE, catch composition, length frequency) but more sampling is needed to collect data on trophic structure and movements of the fish

3- determine the impact of seamounts on the pelagic ecosystem and fisheries (comparison of fisheries and ecosystem characteristics in seamount and open ocean)

4- determine the impact of pelagic fisheries on the seamounts (comparison of seamount characteristics in areas with high and low fishing pressure – examination of the evolution of the fisheries data with time)



Who is involved and how?

SPC, IUCN, IRD, NIWA, CSIRO, University of Hawaii…?

Establish a list of "experts"

Which seamounts should we sample?

It is estimated that more than 30,000 seamounts exist in the Pacific Ocean alone. The number of seamounts inferred from remote sensing and bathymetric data in the world oceans is more than 14,000 (14,675), which almost half reside on the Pacific Plate. A small number have been identified properly (less than 1000), and less (only 100 to 150) have been studied.

Should we focus on already known seamounts, should we explore new seamounts (need to be localized)?

We might identify areas with seamounts and low and high fishing effort to determine the fishing impact.

Are there specific areas we should focus on? (From the fisheries point of view the equatorial area is very important in terms of catch and effort.)

Is the time of the year important?

Should we try and sample at different times of the year, every year? (El Nino / La Nina event)

It is a 5-year project but we cannot expect to do sampling in the final 1 or 2 years.

Extensive sampling is time and money consuming, realizing similar sampling at different times is probably not very realistic.

What do we sample?

We want to characterize the seamounts and the pelagic ecosystem and fisheries in different conditions to determine the impacts (seamount – open ocean – high fishing effort – low fishing effort).

-Oceanographic and environmental parameters: bathymetry (detailed map), SST, temperature vertical profiles, currents at the surface and in the water column, nutrients vertical profiles, POM, geology…

-Biological components: pelagic (ppk, zpk, forage species - DSL, large predators) and benthic

What do we measure on the sampled components?

Biodiversity: list of species (benthic and pelagic), identification needs

Estimates of biomass (benthic, DSL by acoustic, CPUE)

Size of the individuals

Trophic studies (stomachs of large pelagic, isotope)

Horizontal and vertical movements of the fish: tagging, listening stations to measure the residency, acoustic…

Is there a benthic-pelagic relationship on seamounts?

Large pelagics (tunas…) rely mainly on the pelagic, planktonic and DSL organisms to feed. What about the benthic species, is the base of their food web the particulate matter? The tuna and other large pelagic don't feed directly on the benthic species, but is there another component that could be the link between pelagic and benthic? If this link exists, we should try and measure it.

Which boats?

-Deep Ocean Quest and IUCN are planning a 4-month cruise (more opportunities with this boat in other areas?)

-chartered fishing vessels for tagging and stomach samples

-any other research boats from other institutions (NIWA, IRD, CSIRO, others)?

What are the capabilities of these boats?

Which equipment?

Water samples for ppk, CTD

Zpk nets

Mid water trawls IKTM and acoustic for forage/DSL biomass estimates and movements

Longline for large pelagics

Submarine for benthic biodiversity observation, benthic sampling gears

Multibeam scanner for bathymetry and other oceanographic equipment

Listening stations for tagging?

How many samples do we collect?

Who will do the analysis of the samples and data?

Benthic samples: identification experts

Ppk/zpk ID and measurement of biomass

Acoustic interpretation

ID of forage/DSL species

Diet studies, isotope studies

Tagging data

Annex 3. Abstracts of presentations provided by their authors

David Itano, (Pelagic Fisheries Research Program, University of Hawaii –Hawaii)

The central Pacific region is rich in seamounts due to the long-term activity of the volcanic hotspot that created the Hawaiian Islands and the transport of ancient seamounts to the Hawaii region due to Pacific plate movement. This hotspot is responsible for the volcanically active Loihi Seamount located a few miles southeast of the island of Hawaii. The same hotspot created all the islands, atolls and seamounts that stretch over 3000 nautical miles to the northwest of Loihi that include the main Hawaiian Islands, the northwest Hawaiian Islands (NWHI) and the Emperor Seamounts Currently, a small, limited entry domestic fishery for deepwater snappers exists in the NWHI.

The southern Emperor – North Hawaiian Ridge (SE-NHR) seamounts have been the subject of foreign fisheries for decades. A large biomass of the pelagic armorhead (Pseudo-pentaceros wheeleri) was discovered by Soviet trawlers in 1987 and the fishery was fully developed by Japanese vessels after 1969 (Sasaki 1986). Large factory trawlers extracted around 22 – 35K mt/yr during the better years over about a ten year period, followed by an apparent shift in targeting to the alfonsino (Beryx splendens). The take of pelagic armorhead declined sharply after 1978 apparently due to overfishing. Japanese vessels also discovered extensive beds of a deepwater red coral (Corallium secundum) on SE-NHR seamounts in 1965, harvesting up to 200,000 kg/yr with tangle trawls (Grigg 1986). These seamounts have also been exploited by Japanese longline vessels for albacore since 1938, Japanese pole-and-line vessels targeting albacore since ~1973 and are known to aggregate bluefin tuna (Thunnus orientalis) (Yasui 1986).

The main seamounts that have been exploited for pelagic armorhead, corals and tuna include the Kimmei, Milwaukee, Colohan and Hancock Seamounts, all of which have shallowest depths of ~ 250 – 350 m. In 1977, the US gained exclusive economic rights to areas within 200 miles of the main and northwest Hawaiian Islands, bringing the Hancock Seamounts within US jurisdiction, after which directed seamount studies were carried out by the NMFS. In 1984, the Honolulu laboratory of the National Marine Fisheries service and the National Research Institute for Far Seas Fisheries (Japan) held a joint seamount workshop in Shimizu, Japan. The proceedings of this workshop contain a great deal of the documented information on the biology and fisheries of the Hawaii and Emporor seamounts.

Other seamount fields unrelated to the Hawaiian hotspot exist to the north (Musicians Seamounts) and south (Navigator Seamounts) of the main Hawaiian Islands. The Musicians Seamounts are very deep but are still considered to aggregate pelagic species and are targeted by Hawaii-based tuna and swordfish longliners. The Navigator Seamounts are also targeted by Hawaii longline vessels. The Cross Seamount lies within the Navigator Seamount field and is unique in rising to a minimum depth of 330 meters, and has been the subject a relatively high degree of study and survey. The benthic community includes gold and pink corals (Gerardia sp, Corallium regale), two species of pomphret (Taractichthys steindachneri, Eumegestis illustris), broad alfonsin (Beryx decadactylus), large primitive sharks (Echinorhinus cookei, Hexanchus griseus), oilfish (Ruvettus pretiosus), beardfish (Polymyxia japonica) and several other species typical of this depth range.

The Cross Seamount is unique among Hawaiian seamounts in aggregating dense schools of juvenile bigeye and yellowfin tuna that are highly vulnerable to simple handline gears (Itano and Holland 2000). This characteristic has lead to the formation of a specific tuna fishery that has targeted the Cross Seamount and offshore NOAA weather buoys since around 1976. The vessels use a combination of troll and handline methods, landing bigeye and yellowfin tuna at a ratio of approximately 80% bigeye tuna. Generally, the catch consists of relatively small fish of 15 – 30 kgs. The fact that this fishery targets juvenile size fish that are marketed at low value has caused a great deal of conflict and opposition to the Cross Seamount fishery from other segments of Hawaii's pelagic fisheries. These user group conflicts have spawned over 15 years of management action and conflict resolution efforts by the Western Pacific Regional Fishery Management Council. In recent years, the issue has become even more confused by the development of a "short longline" fishery targeting the summit of Cross Seamount (Beverly and Itano 2003). The fishery uses a series of weights and floats to concentrate hooks close to the seamount summit to target large bigeye tuna. The gear can also be easily reconfigured to target the lustrous pomphret (Eumegistis illustris) which has become a desirable market species in Hawaii and for export.

In response to these issues, the Pelagic Fisheries Research Program has funded a number of studies to investigate the fishery characteristics of the Cross Seamount tuna fisheries. The Hawaii Tuna Tagging Project investigated residence times, exploitation rates and movement patterns of yellowfin and bigeye tuna between fishing zones. One of the major objectives of this project was to investigate transfer rates of tuna between the Cross Seamount and other areas exploited by Hawaii-based tuna fisheries (Sibert et al. 2000; Adam et al. 2003). The conventional tagging project tagged over 15,000 yellowfin and bigeye tuna and documented over 2,200 tag recaptures. Over 72% of tag releases and 73% of recaptures were taken on seamounts, highlighting the importance of seamounts to the aggregation and vulnerability of tuna. It was noted that the residence times of tuna on the Cross Seamount were twice as high for bigeye as compared to yellowfin (Holland et al. 1999). Intensive gut content analyses of yellowfin and bigeye tuna caught in association with the Cross Seamount supports the hypothesis that this difference is based on differential feeding behavior between the species (Grubbs in review). It was found that bigeye tuna feed very successfully on a broad range of mesopelagic species of fishes, crustaceans and cephalopods; with myctophid fish and Ommastrephidae shrimps being particularly important. Yellowfin tuna on the seamount fed poorly and generally on smaller amounts of epipelagic prey, such as flying fish, stomatopod larvae and crab megalopae. This work reinforces the importance of fully identifying the characteristics of the mesopelagic boundary fauna and for pelagics; the importance of intermediate seamounts that rise into the mesopelagic zone but do not pierce the epipelagic.

It was suggested that seamounts be classified into categories of: (1) physical / bathymetric and structural; (2)physical / oceanographic (with seasonal and inter-annual variability); and (3) biotic elements. The author suggested that important criteria of seamounts in relation to pelagic species include: the vertical behavior of these species in association with seamounts; the depth and structure of the seamount above ~ 500 meters; the vertical temperature and productivity profiles around the seamount; the characteristics of the mesopelagic boundary community and prey organisms associated with the seamount; and the characteristics of horizontal and vertical water movement.

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Sibert, J., Holland, K., and D. Itano. 2000. Exchange rates of yellowfin and bigeye tunas and fishery interaction between Cross Seamount and near-shore FADs in Hawaii. *Aquat. Living Resour*. 13:

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Alex Rogers, (Institute of Zoology, Zoological Society of London)

Seamounts are raised areas of topography on the seabed with a limited extent at the summit. They vary in size from small hills of less than 100m in height to large complex structures thousands of metres in elevation. Satellite gravity mapping studies have indicated that there maybe as many as 100,000 seamounts in the world's oceans with an elevation of more than 1000m, with the majority of these in the Pacific. Seamounts have become a hot topic in marine science because they have been found to host diverse communities of benthic organisms, many of which are sessile. It has been suggested that the species in these communities are endemic to seamounts within regions, although the lack of knowledge on deep-sea biodiversity in general means that this is difficult to confirm.

Seamounts are also known to host specialist deep-sea demersal fish species, such as orange roughy, pelagic armourhead and alfonsino. They also attract pelagic fish species including billfish and several species of tuna. For this reason, seamounts form an important part of the ecosystem with respect to the GEF-funded South Pacific Fisheries project. This is not only because of the presence of fish on seamounts but also because the benthic communities may potentially be directly or indirectly impacted by fishing activities. There maybe a mechanistic link in the processes that lead to abundant and diverse benthic communities and which attract pelagic fish species. These processes include the trapping of food by the presence of seamounts in the water column, a process known as trophic focusing.

IUCN and DOQ are collaborating on the South Pacific Fisheries project to investigate seamounts in the vicinity of Fiji, Tonga and Samoa in 2007 in a series of 4 cruises. The vessel provided by Deep-Ocean Quest, the RV Alucia is equipped with multibeam sonar and two submersibles, for investigation of biological communities to a depth of 1000m. In addition, the Census of Marine Life Census of Seamounts project (CENSEAM) will also provide support for the project through organisation of science and provision of additional sampling equipment for the planned cruises.

A sampling programme was outlined for the 2007 science cruises with the aim of standardising sampling operations for seamounts in this project and for future projects involving IUCN and DOQ. The protocol entailed a series of oceanographic, geophysical, shallow (down to 40m depth) and deep surveys of benthic communities and studies on the pelagic ecosystems around seamounts. The sampling strategies were discussed, and suggestions were made to enhance the sampling programme through collection and acoustic tagging of large pelagic and demersal fish species associated with seamounts. In addition, the cruise tracks were modified to incorporate seamounts of interest to pelagic fisheries and to reduce the number of sites investigated to allow for more sampling on fewer seamounts. The cruises may now also be supplemented by involvement of Fisheries Research vessels or professional fishing vessels for the purposes of enhancement of studies of pelagic and demersal fish. Collaborations are now being sought amongst Pacific Island States to take part in this study.

Annex 4. Brief description of the sampling equipment required to collect physical and biological data and samples of the seamount ecosystem.

OCEANOGRAPHIC AND ENVIRONMENTAL VARIABLES

Bathymetry / Substrate:

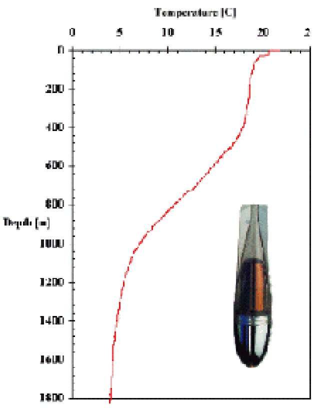
- Multi-beam scanner - Echosounder

A multi-beam scanner is used to scan underwater topography for a swath of the seafloor. This system uses many transmitters and receivers that are spaced over an arc. It can determine the depth of objects by measuring the time it takes for a sound pulse to be emitted by the source and reflected back by the object.

This system uses a number of beams to determine depth rather than a continuous arc of sound, so an average value of depth is taken for a given patch of seafloor. Besides depth, the device can also give an indication of seafloor composition. When the sound pulse returns to the receiver the frequency leak of the signal can be observed: little frequency leak indicates a solid surface while a large range in the frequency of the signal signifies a more porous surface that is not very solid.[2]

Temperature:

- XBT: Expendable Bathythermograph



An e**X**pendable **B**athy**T**hermograph probe is composed of a small projectile with a lead-weighted nose cap and plastic case containing a reel of thin copper wire. The probe is placed in a launcher for deployment at sea. As the probe drops down through the water column, the reel of wire unwinds and transmits the measurement taken to a PC type computer that provides real-time monitoring of the temperature measured.[3]

IFREMER [4]

- CTD: Conductivity, Temperature, and Depth probes

CTDs provide precise and comprehensive vertical profiles and horizontal charts of the distribution and variation of water temperature, salinity, and density. They are lowered on a cable down to the seafloor, and the water properties can be observed in real time via a conducting cable connecting the CTD to a computer on the ship [5]

Global Monitoring Instrumentation Danmark ApS [6]

- Satellite Remote Sensing

Passive radiometers onboard satellites (e.g. AVHRR, ATSR, MODIS) are used to calculate sea-surface temperature (SST) down to 1 km resolution. Large-scale maps of SST can be used to identify water masses and ocean features such as fronts, and can be indicative of underlying processes such as vertical mixing.[7]

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[2] http://www.fao.org/documents/show_cdr.asp?url_file=/DOCREP/003/X6602E/x6602e02.htm
http://www.personal.psu.edu/dsw162/Project3.htm

[3] http://www.ifremer.fr/fleet/equipements_sc/eq/bathythermographe.htm

[4] http://www.ifremer.fr/fleet/equipements_sc/eq/bathythermographe.htm

[5] http://solmar.nurc.nato.int/solmar/education/edu_instrumentation_sens.html

[6] http://www.glomo.dk/prod2i.htm

[7] http://science.hq.nasa.gov/oceans/living/sensing.html

- Water Sampling

CORIOLIS [8]

Not all variables necessary to describe the physics and chemistry of the ocean can be measured electronically with *in situ* or remote sensors. It is therefore important to have a system for sampling water from selected depths. The system used for this is called a rosette. A frame around the CTD carries up to 24 Niskin water sample bottles. A remotely operated device allows the water bottles to be closed at selected depths for sampling. Often, a current meter is added to the CTD/rosette frame. A standard CTD cast, depending on water depth, requires two to five hours to collect a complete set of data.

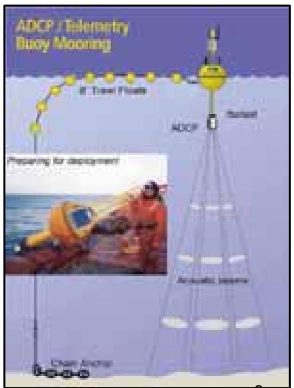
<u>Ocean Color</u>:

- **Satellite Remote Sensing**

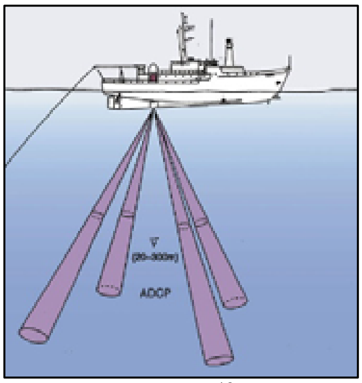
Ocean Color sensors (e.g. CZCS, SeaWiFS, MODIS, MERIS) provide data on water-leaving radiance at different wavelengths, from which measures of euphotic depth and chlorophyll-like pigment concentration can be calculated. The evolution of chlorophyll concentration is a good tracer of the origin of the water masses and synoptic maps of chlorophyll provide an accurate and large-scale picture of the productivity of the surface layers of the ocean.
Ideally ocean color remote sensing data should be calibrated with *in situ* fluorometer and salinometer measurements to convert color data into chlorophyll concentrations.

<u>Currents:</u>

- **ADCP: Acoustic Doppler Current Profiler**



Green Horse Society [9]



SOEST - Hawaii [10]

ADCP measures how fast water is moving across an entire water column. It measures water currents with sound, using a principle of sound waves called the Doppler Effect.
The ADCP works by transmitting "pings" of sound at a constant frequency into the water.

As the sound waves travel, they ricochet off particles suspended in the moving water, and reflect back to the instrument. Due to the Doppler Effect, sound waves bounced back from a particle moving away from the profiler have a slightly lowered frequency when they return. Particles moving toward the instrument send back higher frequency waves. The difference in frequency between the waves the profiler sends out and the waves it receives is called the Doppler shift. The instrument uses this shift to calculate how fast the particle and the water around it are moving.

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[8] http://www.coriolis.eu.org/english/research-vessels/equipment/xbt_ctd.htm
[9] http://www.greenhorsesociety.com/Waves/waves.htm
[10] http://www.soest.hawaii.edu/HOT_WOCE/vcruise/vc5.html

CCD: Carbonate Compensation Depth:

CCD is a depth level in the oceans below which the rate of supply of calcium carbonate (calcite and aragonite) equals the rate of dissolution, such that no calcium carbonate is preserved. Calcium carbonate is essentially insoluble in sea surface waters today, shells of dead calcareous plankton sinking to deeper waters are practically unaltered until reaching the lysocline where the solubility increases dramatically; by the time the CCD is reached all calcium carbonate has dissolved. Calcareous plankton and sediment particles can be found in the water column above the CCD and, if the sea bed is above the CCD, bottom sediments can consist of calcareous sediments called calcareous ooze which is essentially a type of limestone or chalk. If the sea bed is below the CCD, tiny shells of $CaCO_3$ will dissolve before reaching this level so there will be no carbonate sediment.

CCD cannot be measured directly; it is calculated using the dissociation constants of carbonic acid (H_2CO_3), and measurable parameters such as total inorganic carbon dioxide (ΣCO_2) dissolved in sea water, alkalinity, pH, and partial pressure of carbon dioxide exerted by sea water (pCO_2).

Euphotic Depth:

The euphotic zone is the surface of the ocean where sufficient light is available for photosynthesis. Because phytoplankton emit more fluorescence when they cannot photosynthesize, the euphotic depth can be determined by fluorescence measurement with a fluorometer (cf. paragraph on phytoplankton). It can also be estimated from satellite ocean colour data.

Nutrients:

The determination of nutrients is generally based on colorimetric methods. Nutrients are measured by firstly collecting water samples at different depths in bottles on the CTD rosette. These are then analyzed in the laboratory with a nutrient analyzer. This machine adds chemicals that turn the water blue when they bind to nutrients. The darker the blue, the more nutrients in the water. The machine measures the intensity of the color and compares it to a standard curve to determine the amount of nutrient in the sample.[11]

Dissolved oxygen (DO):

The most common measurement method is the use of DO probe and meter. DO can also be measured with field kits, or by the Azide-Winkler titration method. Theses two methods require that samples be collected into BOD (Biological Oxygen Demand) bottles, which are used to sample water in the specific conditions required for DO measurements. They are fitted with a mechanism allowing water to flush through the bottle while air escapes through a port.[12]

Particulate Matter:

Particulate matter can be measured using a transmissometer that is an instrument used to measure transmission or beam attenuation in water, over a fixed distance; it indicates the quantity of particulate matter in the water.

11 http://coexploration.org/bbsr/classroombats/html/body_ocean_properties.html#PhytoplanktonPigments

12 http://www.ecy.wa.gov/programs/wq/plants/management/joysmanual/4oxygen.html

PELAGIC COMMUNITIES

Phytoplankton:

- **Collection and enumeration of cells:**

Water samples are collected with Niskin bottles to minimize the loss and the disruption of cells. Samples are immediately preserved with Lugol's solution, and stored in the dark. For enumeration, samples are settled for at least 24 hours in a sedimentation chamber then phytoplankton cells are counted using an inverted microscope.

- **For qualitative sampling using a fine mesh net:**

The phytoplankton net is made of very fine mesh (<64µm), and is used to collect algae and other phytoplankton from the water column. It will provide presence/absence information and can aid in the identification of rare species. The net is a vertically towed net lowered slowly to the desired depth, and then pulled up more quickly, concentrating phytoplankton in the attached sample jar as it rises towards the surface.

- **Pigment measurement (filtration about 20L water)**

The amount of chlorophyll-a-pigment in sea water is related to the amount of plant material and is thus used to measure plant biomass in the ocean. Most phytoplankton also contain what are called accessory pigments often specific to a group of phytoplankton.

Phytoplankton chlorophyll-a can be measured by using fluorescence. Water samples are filtered and the phytoplankton is collected on the filters. The pigments are then extracted from the phytoplankton and placed in a fluorometer. The fluorometer shines light of a certain wavelength (blue) on the pigment sample and the chlorophyll-a in the sample fluoresces back at a different wavelength (red). The amount of fluorescence is proportional to the amount of chlorophyll-a.

Phytoplankton accessory pigments are measured using by High Performance Liquid Chromatography (HPLC). This machine separates the pigments from a water sample and gives a relative measure of the groups of plants that are present in the water.

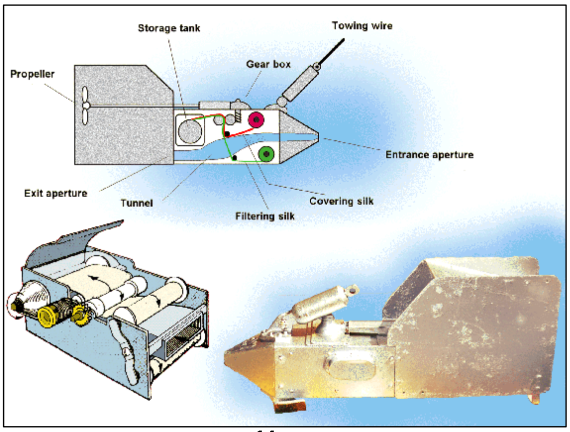
- **Productivity measurement (requires incubation on board)**

Productivity (i.e. production of carbon by photosynthesis) can't be directly measured, but rather is derived from a combination of other measurements. Net primary production is the amount of carbon created, less the amount reused in cellular respiration. To estimate net primary production, chlorophyll data is analyzed according to sea surface temperature, incident solar irradiance and mixed layer depths. *In situ* incubation techniques are typically used to measure primary production. Seawater samples are collected at different depths in light and dark bottles; they are then incubated for predetermined durations at temperatures corresponding to the collection depths. By measurement of oxygen concentration before and after incubation, and with suitable calculations according to the time of incubation, carbon production and respiration can be expressed for each sample.[13]

[13] http://hahana.soest.hawaii.edu/hot/protocols/chap14.html

Zooplankton:

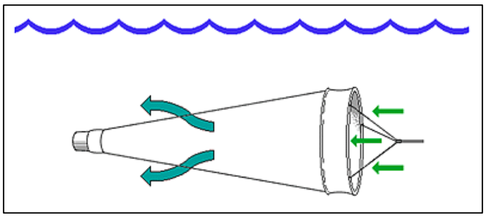
- **CPR: Continuous Plankton Recorder:**



The Sir Alister Hardy Foundation, UK. [14]

The CPR is a plankton sampling instrument designed to be towed from merchant ships of opportunity, i.e. during their normal sailings. The CPR works by filtering plankton from the water over long distances (up to 500 nautical miles) on a moving filter band of silk. The silk band filter is wound through the CPR on rollers turned by gears, which are powered by an impeller. On return to the laboratory, the silk is removed from the mechanism and divided into samples representing 10 nautical miles of towing before being examined. This instrument allows the determination of species and also provides information on their relative abundance and distribution.[15]

- **Standard plankton net:**


Environmental Laboratory–US Army Corps of Engineers [16]

Towed by a research vessel, plankton nets have a long funnel shape that allows them to catch different sizes of plankton organisms simply by changing the mesh size of the net (1mm and above for jelly plankton and fish larvae, 200µm-1mm for large zooplankton, 64µm-200µm for small zooplankton and less than 64µm for phytoplankton). The net ring usually measures 1 meter in diameter. A collection cylinder is placed at the cod-end of the funnel. They represent an excellent technique for sampling large quantities of water; however, calculating the amount of water filtered by the net can be difficult if quantitative data are desired.

- **Bongo net:**

Bongo nets provide a vertical sample of the zooplankton from a depth to the surface. It is made of two identical nets that can be towed either vertically or obliquely generally at a speed of 1 m/s. It gives an idea of the plankton present within a depth range. This type of net is made in a wide variety of size. The standard mesh size is 500µm but it can vary from 20µm to 1mm. The hoops diameters are usually of 60 cm.


NOAA – Explorer [17]

[14] http://www.sahfos.ac.uk/cpr_survey.htm
[15] http://www.sahfos.ac.uk/cpr_survey.htm
[16] http://el.erdc.usace.army.mil/zebra/zmis/zmishelp/oblique_plankton_tow.htm
[17] http://oceanexplorer.noaa.gov/technology/vessels/mcarthur/media/bongo_mc.html

- **Multi net:**


F.M.Porteiro / MAR-ECO / ImagDOP[18]

A multi net is an opening/closing net equipped with several nets which collect zooplankton samples from different depths in the water column. The net is lowered and towed vertically from a depth to the surface by a multiconductor cable and the opening/closing of the nets are controlled from on board the ship.

- **Epibenthic Sled Net Sampler:**


Fisheries and Oceans – Canada[19]

Epibenthic sleds are used to sample zooplankton just above the sea floor. It consists of a rectangular steel frame fitted with a 1mm mesh net. When the net hits the bottom, it opens a door at the front, the net is then dragged along the bottom and any zooplankton within around 1m above the sea floor is captured. This instrument is similar to the larger "epibenthic sledge" used for benthic communities sampling.

- **Neuston nets:**


MOC –NOAA[20]

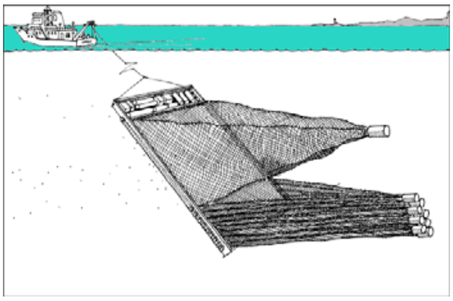
Neuston nets are designed to collect surface plankton samples. The net is a 1 by 2 meter net and is sometimes placed together to make a double neuston. The net is towed through the water at about 2 knots with half the net in the water and half out.

[18] http://www.coml.org/edu/tech/collect/planktonnets1a.htm
[19] http://www.pac.dfo-mpo.gc.ca/sci/osap/projects/plankton/electron_e.htm
[20] http://www.moc.noaa.gov/ot/visitor/otneuston.htm

Micronekton - DSL (Deep Scattering Layer):

Present technology to detect and estimate micronekton biomass includes a variety of acoustic and optical sensors, mounted on various platforms; these are often used in combination with real-time monitored and controlled active and passive gear for calibration or ground truthing purposes, i.e. directed physical sampling in the sound scattering layers or shoals.

- **MOCNESS**



Incze,L.- Bioscience Research Institute, University of Southern Maine [21]

The MOCNESS (Multiple Opening and Closing Net and Environmental Sensing System) is a computer controlled net system used to collect plankton samples from specific depths in the water column. As the net system is towed through the water, individual nets can be opened within target depth 'bins.' This ability to collect samples from discrete depths allows researchers to determine the vertical distribution of the organisms they are studying.

- **Rectangular Midwater Trawl** (**RMT 8 / RMT 12 opening closing net)**:

© Copyright 2006 – OSIL [23]

This is a controlled opening and closing net system designed for the capture of shallow, midwater and deep zooplankton and micronekton in the open ocean. The net is opened and closed using a down wire signal from the ship to operate the mechanical release. The RMT system can be tailored to individual needs with regard to net sizes and numbers. RMT8, which has an 8 sq meters mouth area, is the most common design.[22]

- **Acoustic sonar (ship-mounted EK 500 / transferable EK60);**

Installation of acoustic sonar ©Fadio/IRD-IFREMER/C.Girard [24]

An acoustic sonar system is an apparatus used for obtaining information about underwater objects by transmitting sound waves and observing the return echoes. Sound is generated in discrete pulses; any target (e.g. fish) in the path of this pulse will return an echo that is picked up by a receiver, amplified, and converted into some visible sign on the display device (paper recorder or screen). It can be used to localize fish schools and to estimate their biomass. Acoustic sonar can be ship-mounted or towed behind the boat according to the models.

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[21] http://gmri.org/ http://www.at-sea.org/missions/maineevent6/docs/mocness.html
[22] http://www.osil.co.uk
[23] http://www.osil.co.uk/web/osil/osil.nsf/a/5A868B1996DEE0D380256D0A004E78A9?opendocument
[24] http://www.fadio.ird.fr/fr/fieldreports3%20fr.htm

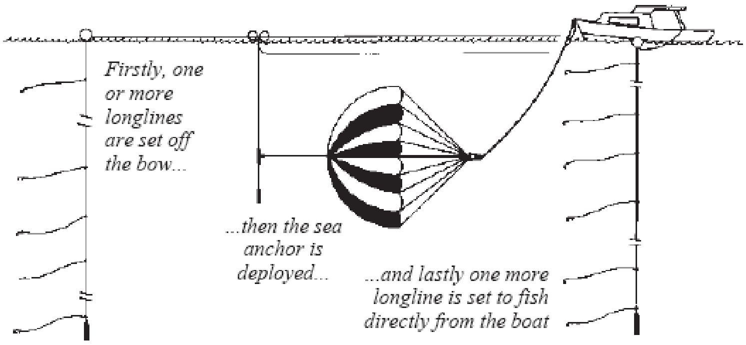
- **IKMT net: Isaacs-kidd Midwater trawl**

SOLMAR [25]

IKMT nets are used to sample small pelagic species (e.g the DSL) in addition to plankton and the particulate content in the ocean. They usually have a mesh size of 3-4 mm, which gradually decreases down to 500 µm at the cod end. The size of the mouth is usually 1 sq meter. The net is towed behind a boat for a specified period of time and at a known location for later sorting, classification and mapping.

Large pelagics:

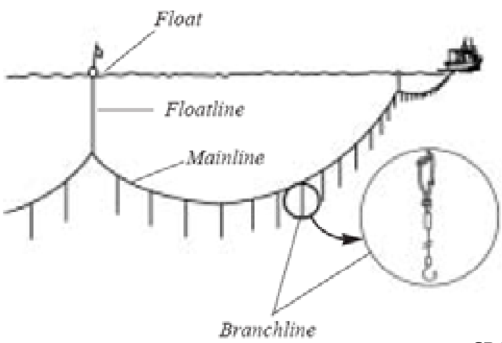
- **Fishing gears (vertical longline, horizontal longline, purse seine)**



Vertical longlining using a sea anchor

SPC

Vertical longlining is a simple way to fish in deep water for oceanic fishes. A basic vertical longline comprises a single long weighted mainline suspended from the surface and which reaches down to a depth of 300m or more. Connected to the mainline are a series of branchlines, each of which carries a baited hook. Sea anchors or parachute anchors are used for vertical longlining and other FAD-fishing methods. The sea anchor will prevent the fishing boat drifting as a result of wind and instead cause the boat to move in the same direction as the current.[26]



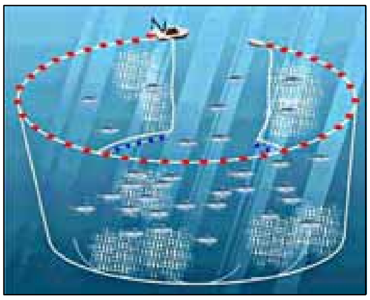
SPC

Horizontal Longlining uses a long mainline (5 to 100 n miles long) made of tarred rope nylon monofilament, to which hundreds or thousands of branchlines are attached, each with a single baited hook. The line is suspended in the water by floatlines attached to floats, which may have flagpoles, lights, or radio beacons.[27]

[25] http://solmar.saclantc.nato.int/solmar/education/edu_instrumentation_sens.html
[26] http://www.spc.int/coastfish/Fishing/Vert_E/Chapter2VLL.pdf
[27] http://www.spc.int/coastfish/Sections/Development/FDSPublications/FDSManuals/PH/Chap1s.pdf

Purse Seine fishing:

Purse-seine fishing vessels use long nets, approximately one mile in length, to encircle large pelagics. The net is framed with floatline and leadline and is usually about 200-300 meters high. The bottom of the net is closed by drawstrings much like a drawstring purse.



Europacific Tuna LTD [28]

- **Tagging / listening stations:**

Insertion of VEMCO V9 Acoustic tag - SPC

Listening stations can be used to locate pelagic species equipped with acoustic tags. Attached under FAD, they consist of hydrophone / datalogger combination that detect and record the signals emitted by the acoustic tags. They measure how long the tagged fish stays in the proximity of the FAD.

A VEMCO VR2 Listening Station - ©FADIO/IRD - IFREMER/ M.Taquet [29]

Insertion of an archival Tag [30] *– National Marine Fisheries service, Barbara Block- Stanford University*

Other types of tags, such as archival tags and satellites tags, are also used for monitoring the movements of large pelagic species. Archival tags record and store information such as internal and/or external temperature, depth and light at chosen regular intervals of time, but they must be returned in order to retrieve the data. Satellites tags avoid the problem of tag recovery because they transmit information on a pre-programmed release date via an orbiting satellite.

Satellite tag - SPC

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28 http://www.europacifictuna.com/purseseine.htm
29 http://www.fadio.ird.fr/fieldreports4.htm
30 http://www.afrf.org/files/ongoing_research/shogun2003tag.jpg

BENTHIC COMMUNITIES

- **Beam Trawl**

NIWA - Censeam [31]

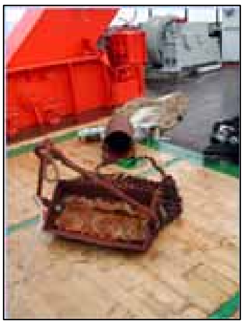
Beam trawls are bottom trawls with the horizontal opening of the net maintained by a beam made of wood or metal, which may be 10 m long or more. The vertical opening of beam trawls is usually less than 1m high.

- **Epibenthic sledges:**

Epibenthic sledge, equipped with additional video and still cameras
Bernd Christiansen, Universitat Hamburg [32]

Epibenthic sledges consist of a rectangular steel frame with a mesh net (often more than one) attached to it. Towed along the ocean floor, its weight causes the sledge to scrape into the benthos, collecting any organisms on the surface or in the first few centimeters of sediment. It also collects the organisms in the water column just above the benthos. A video camera is often attached to the net. Epibenthic sledges are good for collecting relatively mobile (but not fast swimming) benthic organisms, but they can damage delicate organisms

- **Dredges:**



Bernd Christiansen - Universitat Hamburg [31]

Dredges are used to sample animals from the sea floor, on rough ground where more delicate sampling gear like the epibenthic sledge is likely to be damaged. The dredge consists of a rigid steel frame to which a coarse net, sometimes made from chain netting, is attached.

- **Deepwater dropline gear**

Commercial bottomfish gear can be used to sample the benthic finfish community to depths of approximately 400 meters. The use of thin, high strength Spectra mainlines will allow deep line fishing with little impact from drift and current. The capture of large benthic predators provides the added bonus of collecting specimens from gut analyses.

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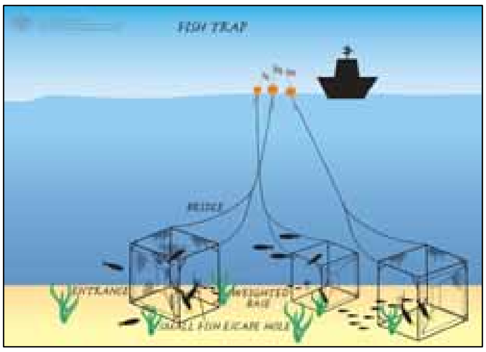
[31] http://censeam.niwa.co.nz/outreach/censeam_sampling
[32] http://www1.uni-hamburg.de/OASIS//Pages/public/Meteor/gear.htm

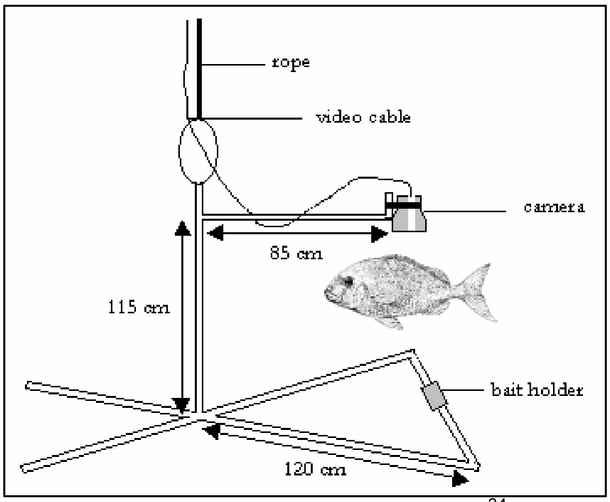
- **Fish traps**



Work passively and can be useful for collecting small cryptic species of fish and invertebrates.

Australian Fisheries Management Authority [33]

- **Underwater video used in conjunction with bait stations**



Bait stations with video cameras can be used to document the presence of many benthic species without the difficulties involved in their capture. Video documentation is particularly attractive for observing species that are not vulnerable to trap or hook and line gear or may be so large as to make capture difficult (ie shark species). Also, the method is non lethal.

Department of Conservation – New Zealand [34]

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http://www.msc-smc.ec.gc.ca/education/msi/glossary/glossary_t_e.html
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http://ilmbwww.gov.bc.ca/risc/o_docs/coastal/subtidal/subtidal-44.htm

Thanks to: The national Institute of Water and Atmospheric Research (NIWA -NZ)

[33] http://www.afma.gov.au/information/students/methods/traps.htm
[34] http://www.doc.govt.nz/Community/001~For-Schools/003~Field-Trips/004~Waikato/Te-Whanganui-A-Hei-Marine-Reserve/019~Focus-on-Monitoring-(Study-Sheet).asp