An overview of the REMIGE project : "Behavioral and demographic responses of marine top predator to global change in the Indian Ocean"

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Introduction

The climate-driven changes play at different time- and space-scales. They affect the population dynamics and the functioning of the ecosystems through availability, abundance and spatial distribution of forage resources. Understanding the combined effects of climate change at various scales and their modulation by the biological interactions remains a real challenge in the marine ecosystems (Hsieh et al, 2005). It is impossible to embrace the whole complexity of the biological systems, for each trophic level and at a large scale because observations for the intermediate trophic levels are lacking. In this project, marine top predators are used as bio-indicators of climate fluctuations. The working hypothesis is that apex predators can integrate such fluctuations and the propagation of biological responses along the trophic pathways. We want to promote a comparative approach to study the responses of different categories of top predators (large fish, seabirds, marine mammals) in different biomes (from tropics to pole). We can expect contrasted responses because of different foraging strategies and different life histories among the selected apex predators (Table 1). Ultimately, the question is to know which biomes/ecosystems are likely to be the most affected by sustained environmental changes (temperature rise, regime shift…). We propose to address this issue using an integrated approach by coupling observations (behaviour, foraging strategies, life histories of top predators) and ecosystem modelling (to simulate the interactions across the trophic webs).

Table 1 – Environmental and life traits differences across the tropical, temperate and polar biomes

	Tropical	Temperate	Polar
Sensitivity to ENSO	Strong	Moderate	Low
Seasonality	Low to Moderate	Moderate	Strong
Ocean heterogeneity	Low	Moderate	Strong
Primary production	Low	Moderate	Strong
Trophic web	Complex	Complex	Simple
Population dynamics of fish	Fast	Intermediate	Slow
Population dynamics of seabirds and marine mammals	Slow	Moderately fast	Moderately fast

Objectives

REMIGE, a 3-year project (2006-2008), aims at understanding and forecast how the climate change and induced biological responses are likely to affect the functioning of marine ecosystems in the Indian Ocean. Four interconnected biomes are considered: Antarctic, Sub-Antarctic, subtropical and tropical, by involving various research teams and institutions specialised in each of these biomes. Finally, this inter-disciplinary project:

1) will make extensive use of available long-term data and acquire new large-scale information on the at-sea distribution, abundance and reproductive performance of marine predators,

2) to characterise the habitats exploited by top predators and

3) to generate predictions of the secondary and tertiary production of different biomes of the Indian Ocean based on oceanic, biogeochemical and ecosystem models.

Study areas and biological models

The 4 biomes studied in the project are presented in Figure 1. Southern and tropical regions are often studied separately although same types of climate events (ENSO, IO dipole) and similar propagating features (Rossby waves, Antarctic Circumpolar waves) are influencing them. In this project, the behavioural and demographic responses will be studied on common periods of time for all 4 biomes. There are time series available on the mid or long term for environmental parameters (physical observations) and for primary production (by satellite, SeaWifs and Modis), but no series exists for the intermediate trophic levels (zooplankton, micronekton…). The relationship between environmental variability and these trophic levels remains a "black box" for which empirical data are surrogated by modelling. On the other hand, long time series exist for predators such as fish (tuna), seabirds and marine mammals. These predators integrate the physical and biological fluctuations at different trophic levels (Croxall et al. 2002) and exhibit sensitivity to these changes (Aebisher et al. 1990). Large-scale movements in the pelagic realm and foraging strategies have been directly related with the distribution, abundance and availability of prey. Top predators do not explore their environment randomly; they rather target some very productive areas also exploited by the fisheries and characterized by oceanic features (thermal or sea colour fronts, eddies, sea mounts…).
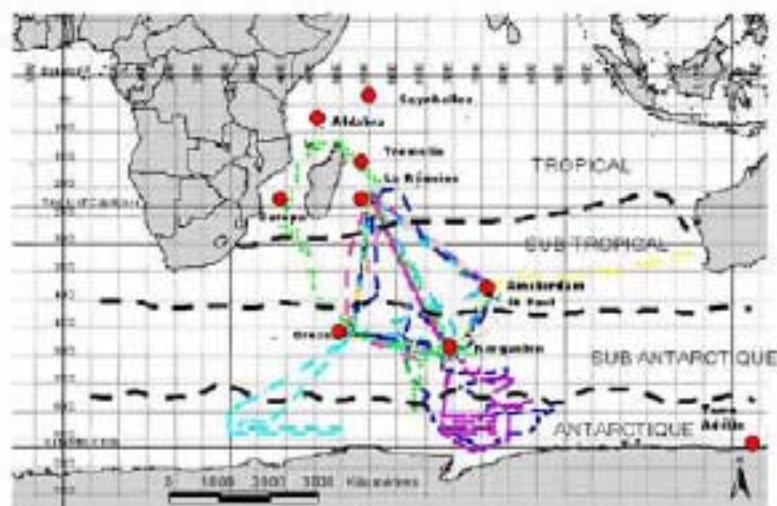

Fig. 1 – Delineation of the 4 biomes under study. The red dots indicate the terrestrial study sites for seabirds and the coloured lines depict some trajectories of seabirds and marine mammals in the southern Indian Ocean.

In the tropical region, the biological models studied will be tuna for fish, red-footed boobies and great frigatebirds for seabids. In the subtropical and subantarctic regions, they will be southern bluefin tuna for fish, albatrosses and petrels for seabirds. In the Antarctic biome, they will be the Patagonian toothfish, the Southern fulmar, snow petrel and emperor penguin for seabirds and some pinnipeds. Most of the datasets fort these animals are collected by the French partners (8 different teams). Two foreign institutions are also associated to REMIGE as they have expertise and data on some key species in the project: the CSIRO (Hobart, Australia) for the Southern Bluefin Tuna; and the Marine & Coastal Management of Cape Town (South Africa) for some boobles of the East African coast.

Structure of the REMIGE project

Four types of observations and methods will be used:

- oceanographic databases and ocean model outputs;
- demographic surveys made continuously during 50 years and concerning 18 seabird species, 3 marine mammals species and 6 fish species, a world-unique dataset;
- at-sea observations on distribution of top predators (tracking and transects) that will be complemented, during the project, by studies on the winter distribution of some species (seabirds and marine mammals);
- statistical and geostatistical tools, and demographic models.
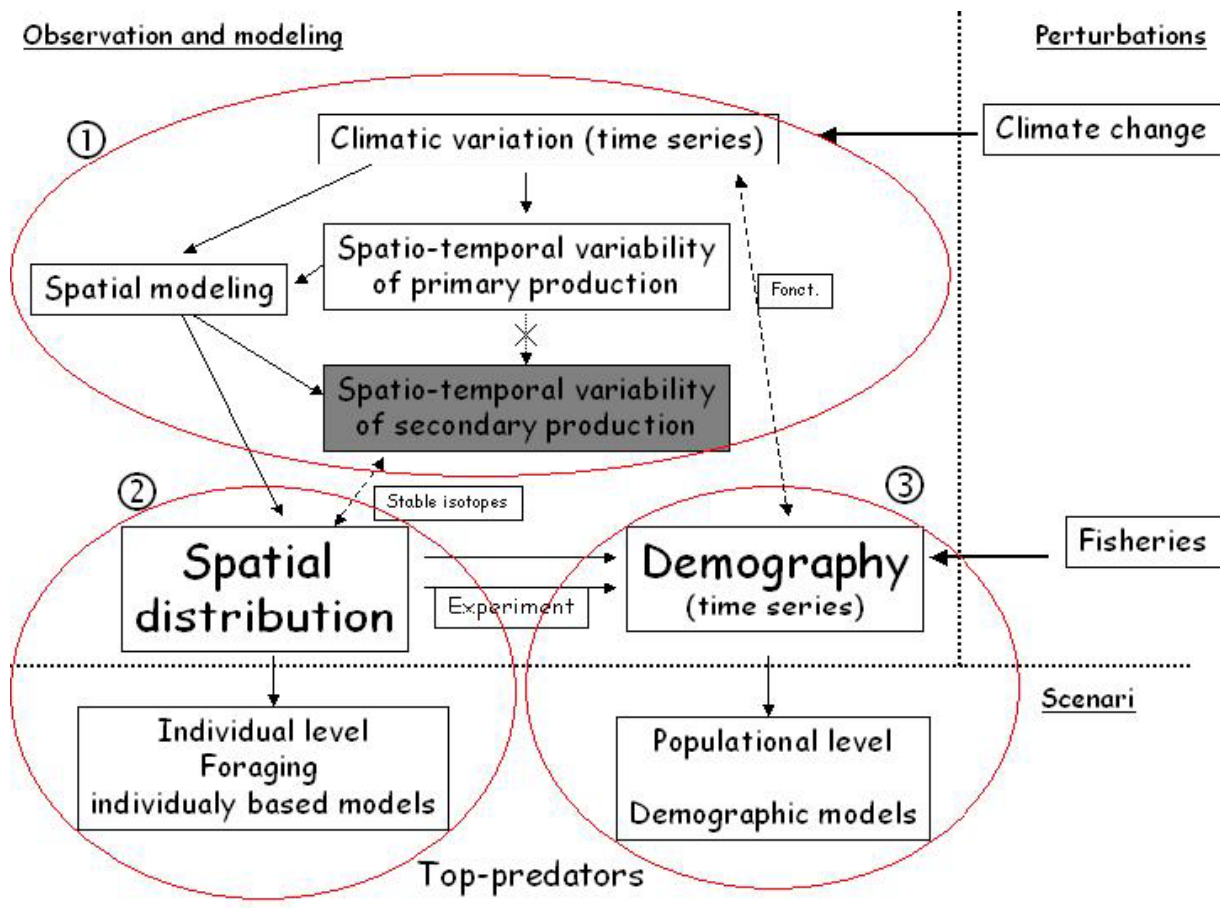
The project will include 3 working packages:

WP1 - Climatic, physical and biogeochemical environment

Environmental observations and model outputs will be organised in a relational database for remote access through Internet and a dedicated application will be designed. Physical and biological models will be coupled to simulate fields of potential forage for top predators

1a) Implementation of a web application to access and process environmental data

- Design a relational database interconnecting 3 components :
  - Discrete oceanographic stations, CTDs and XBTs and gridded fields of *in situ* measurements
  - Satellite fields (SST, SSC, altimetry)
  - Model outputs (gridded)
- Data extraction and representation (Live Access Server) : fixed images, graphics resulting from specific queries and animations
- Production of derived indices

1b) Coupling physical and biological models

- Reconstruction of physical & biogeochemical fields, and size spectra of prey in a continuous space (gridded fields at each time steps)
  - Physical models : OPA/Mercator 25 km resolution, and ROMS (25 to 8 km)
  - Biogeochemical model : PISCES nutrients + different functional groups of zoopk
  - Ecosystem model : APECOSM-1 from nutrient fields to distribution of forage along a size spectrum (on-line coupling with PISCES)
- Addressing both basin-scale and regional-scale : two focus areas, Mozambique Channel and Kerguelen area, with high resolution models

WP2 - Spatial distribution of top predators

To understand how top predators can change their geographic distribution according to the climatic fluctuations

- Characterizing habitats of top predators and behavioral responses to the environmental variability
  - Compiling and organizing (database) tracking data of marine mammals, seabirds and tuna (SBT)
  - Standardizing the baseline of N15 stable isotops across the different biomes

- Modelling responses of predators
  - Individual-based models : seabirds movements (albatrosses) forced by the forage distribution (APECOSM-1 simulation)
  - Numeric model (eulerian) to describe tuna movements/distribution from forage : APECOSM-2

WP3 – Demography of top predators

From the long term demographic surveys, to check correspondence between simulated interannual variations of forage resources and success/failure of vital descriptors, and to estimate the shape of the functional response. After validation, the models will be used to forecast response to various IPCC scenarios.

- Comparative analysis of trends : environmental series vs demographic surveys
    - Statistical analyses (wavelets, DFA…)
    - Matrix models
- In situ experiments
    - Simulate environmental changes on seabirds to study the physiological and behavioral adaptive responses
- Simulation study of the impacts of climate change scenarios (IPCC)
    - Distribution of forage and top predators (APECOSM)
    - Stochastic demographic models : survival, fecundity
    - Behavioral models : foraging strategies

Resources

The funding source is France, through the newly created ANR (*Agence Nationale de la Recherche*) an equivalent of the US National Science Fundation. The budget for the 3 years of the project is 500 000 €, excluding salaries of the permanent staff attached to the 8 French cooperating institutions and the 2 foreign institutions (CSIRO-Hobart , Australia, and Marine & Coastal Management, South Africa). The bulk of the budget is used to hire temporary staff.

The staff to be hired is:
- For WP-1 : 1 postdoc for coupling physics and biogeochemistry (31 months) and 1 computer engineer for database and Web developments (18 months)
- For WP-2 : 1 computer engineer (16 months), 1 technician for stable isotopes (5 months) and 1 postdoc in IBM modelling (18 months)
- For WP-3 : 1 postdoc for modelling populations responses under various IPCC scenarios

Deliverables

There will be 4 types of products:

1) Peer-reviewed papers in international journals in Oceanography, Ecology, Management and Conservation;

2) Organisation of an international workshop in the framework of GLOBEC, CLIOTOP and Southern Ocean GLOBEC "Effect of climate change in the Indian Ocean on top predators";

3) Final report of the programme, for non expert readers; Information to fisheries and southern territories containing scenarios of the impact of climate change and fisheries on top predators;

4) Create a Web site describing the project and presenting the results.

References

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