Trophic Ecology of Four Apex Predators of the Pelagic Ecosystem in the Indian Ocean

Lancet fish, Yellowfin tuna, Bigeye tuna & Swordfish

Michel Potier [1], Francis Marsac [2], Vincent Lucas [3], Richard Sabatié [4], Olivier Maury [1] , Jean-Pierre Hallier [1] , Yves Chérel [5] & Frédéric Ménard [1]

[1] IRD, Reunion Island
[2] IRD, Sète, France
[3] Seychelles Fishing Authority, Seychelles
[4] ENSA, Rennes, France
[5] CNRS-CEBC, Chizé, France

IRD
Institut de recherche pour le développement

THETIS

- « Who eats who ? » is a relevant approach to understand the characteristics of an ecosystem and how the different functional groups interact

Goals


Yellowfin
(Thunnus albacares)

- Compare the diet of four major predators
  - Study the degree of overlapping of feeding regimes among predators
  - Estimate the size ratios between predators & prey
  - Introduce a stable isotope perspective

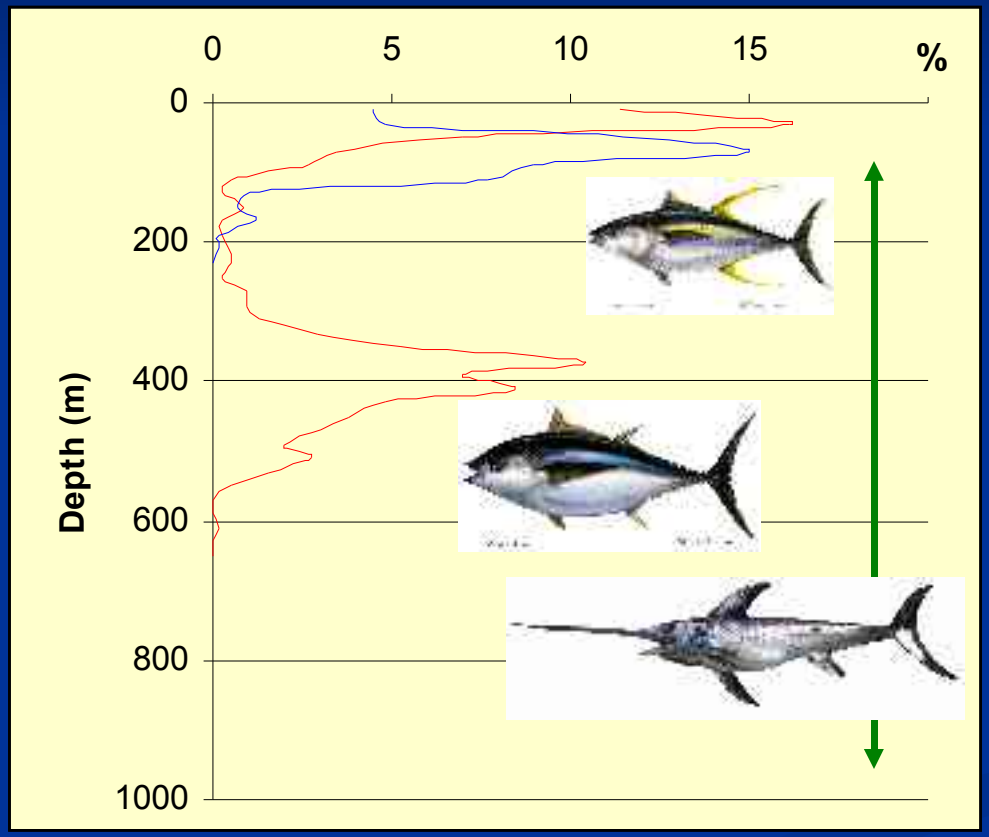

Lancetfish *(Alepisaurus ferox)*


Swordfish
(Xiphias gladius)

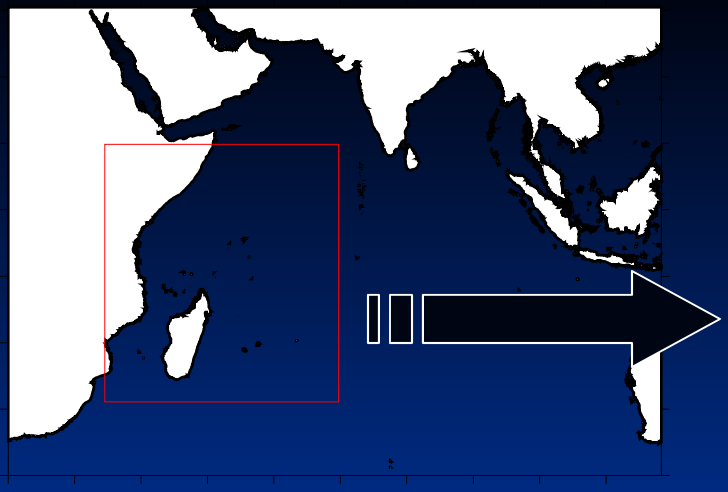

Bigeye *(Thunnus obesus)*

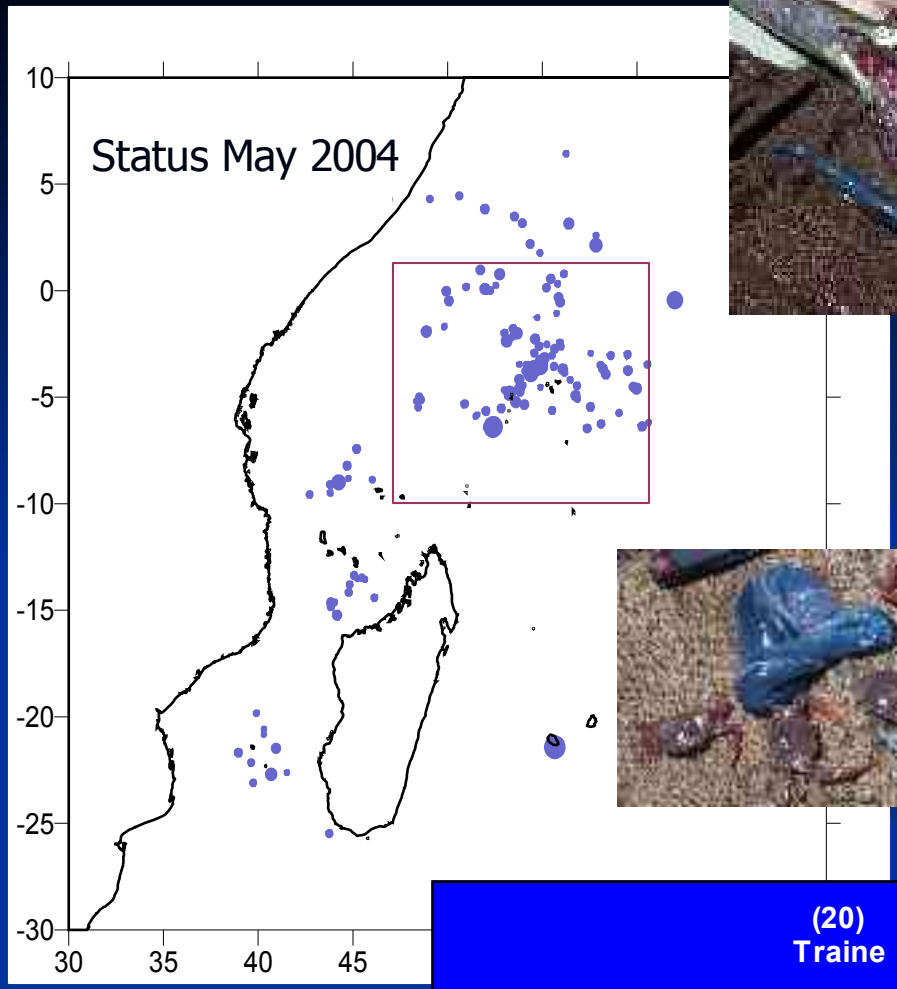
Vertical Distribution : where do they live ?

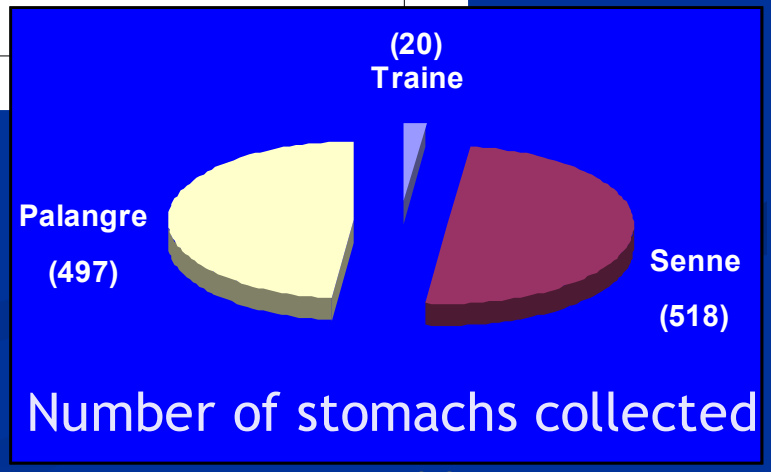
What we know from ultrasonic tagging



- The 4 predators occupy different depth ranges :
  - **Yellowfin : 0 - 200 m**
  - **Bigeye tuna : 0 – 500 m**
  - **Swordfish : 0 – 700 m**
  - **Lancet fish : ??**



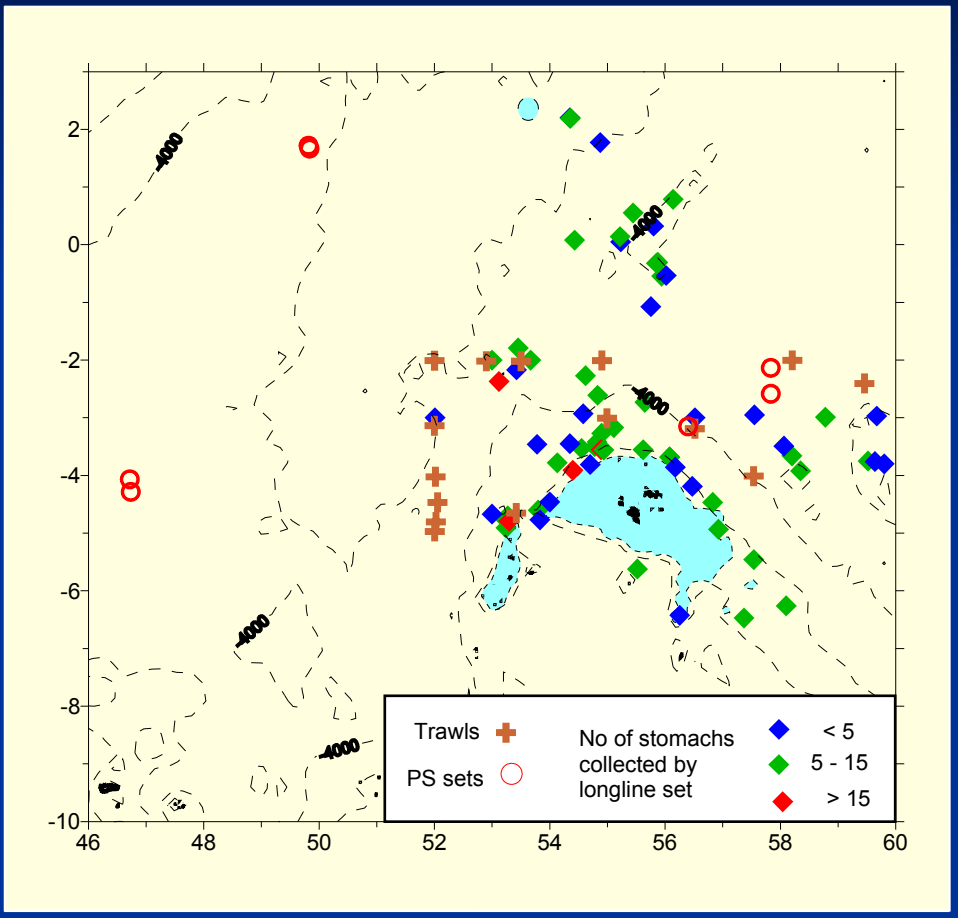




Study area

> 1100

Survey implementation



19 months (Aug. 01/Feb. 03)
67 LL sets and 10 PS sets
1 oceanographic cruise R/V

- 47 CTD profiles (T & DO)
- 15 midwater trawls

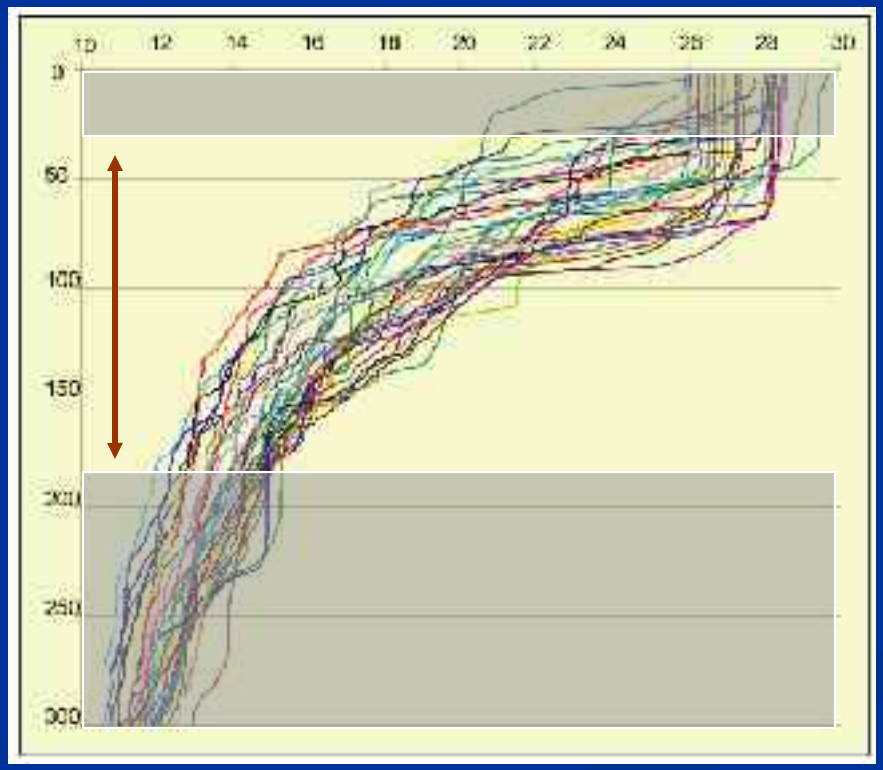
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2001												
2002												
2003												
Total	150						111			163		

		Lancet fish	Yellowfin	Bigeye	Swordfish	Total
LL	non-empty stomachs	128	110	17	123	378
	% empty	8	13	41	16	
	Size range (cm)	15 - 170	32 - 161	33 - 168	51 - 192	
PS	non-empty stomachs		34	12		46
	% empty		0	0		
	Size range (cm)		40-150	40-100		

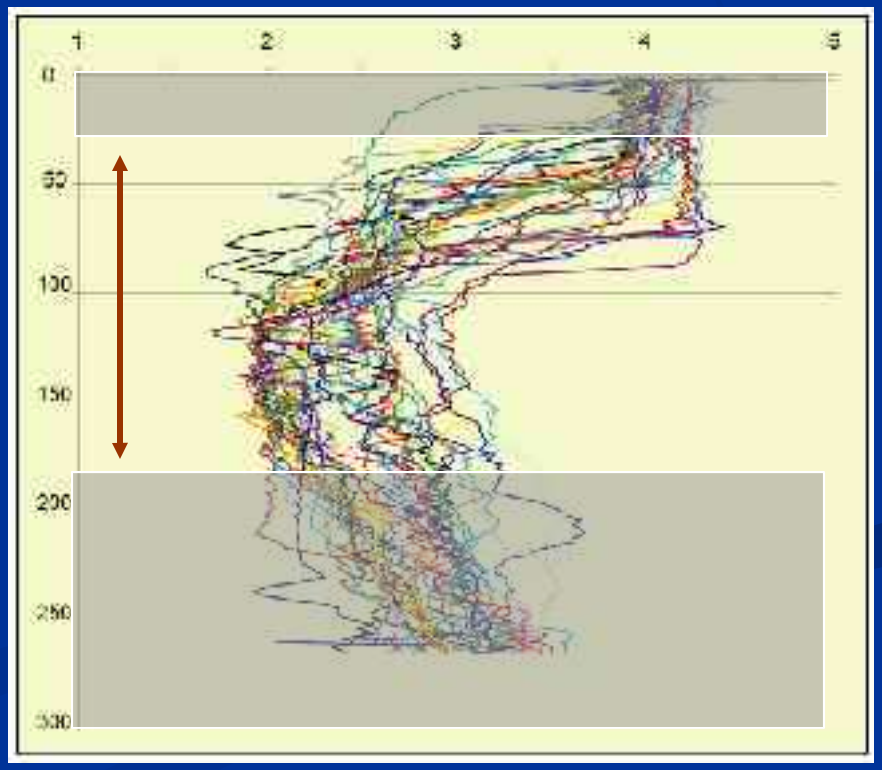
The environmental context :

Temperature & DO profiles and depth range sampled by the longline gear

Temperature



Dissolved oxygen



1- Dietary Analysis

A **Weighing the stomach content**

B **Sorting in large categories**

Fish Molluscs Crustacea

The less abundant categories (ie. molluscs and crustacea) are weighed then the main category (ie. fish) is obtained by difference

C **For each category**

Accumulated food ← sorting → Fresh Food

Counting the remarkable organs (otoliths, beaks, mandibles,,…)

For each item
Species identification, counting, measuring the remarkable organs or entire individuals.

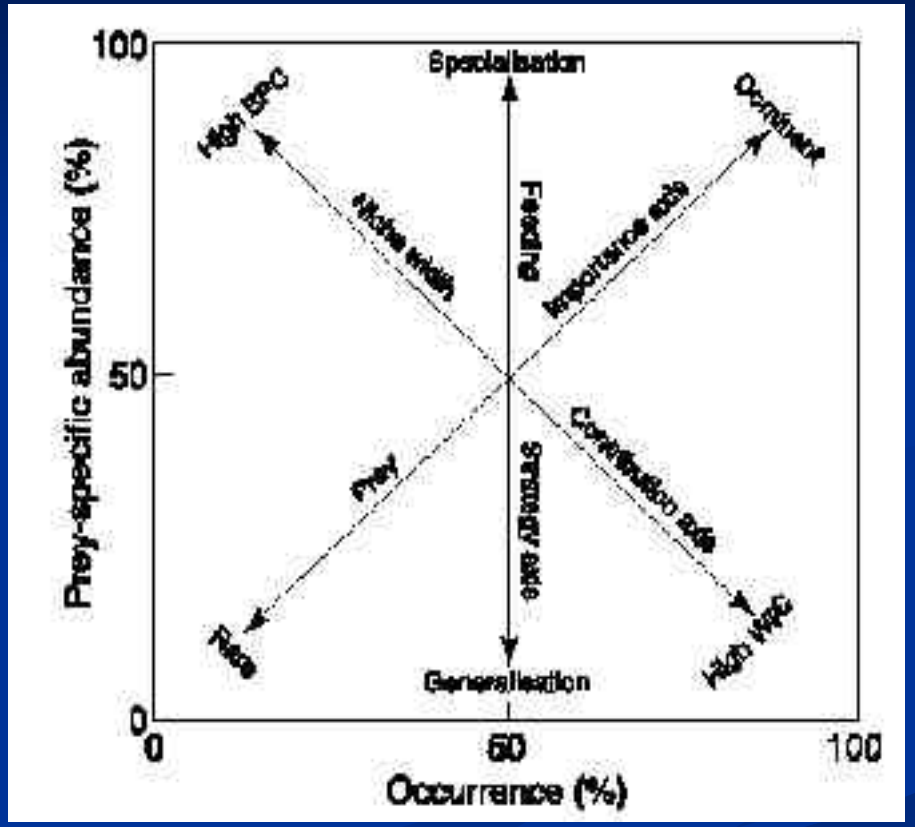
Reconstituted weight of the diet

2- Prey Dominance Indices

- Modified Costello diagram (Amundsen et al. 1996)

$$\text{Occurrence}(\%) = \frac{\sum \text{stomachs with prey A}}{\sum \text{stomachs with prey}}$$

$$\text{Prey-specific abundance}(\%) = \frac{\sum \text{prey A (number, weight)}}{\sum \text{all prey in stomachs with prey A}}$$



- Index of Relative Importance (IRI)

(Pinkas et al. 1971)

$$IRI_A = (N_A\% + P_A\%) \times F_A\%$$

Number N, Weight P, Occurrence F

3- Similarity Index

- Morisita & Horn Index of similarity (Magurran 1988)

$$C_{mh} = \frac{2\sum_{i=1}^{S} an_i \times bn_i}{(da + db)(aN \times bN)}$$

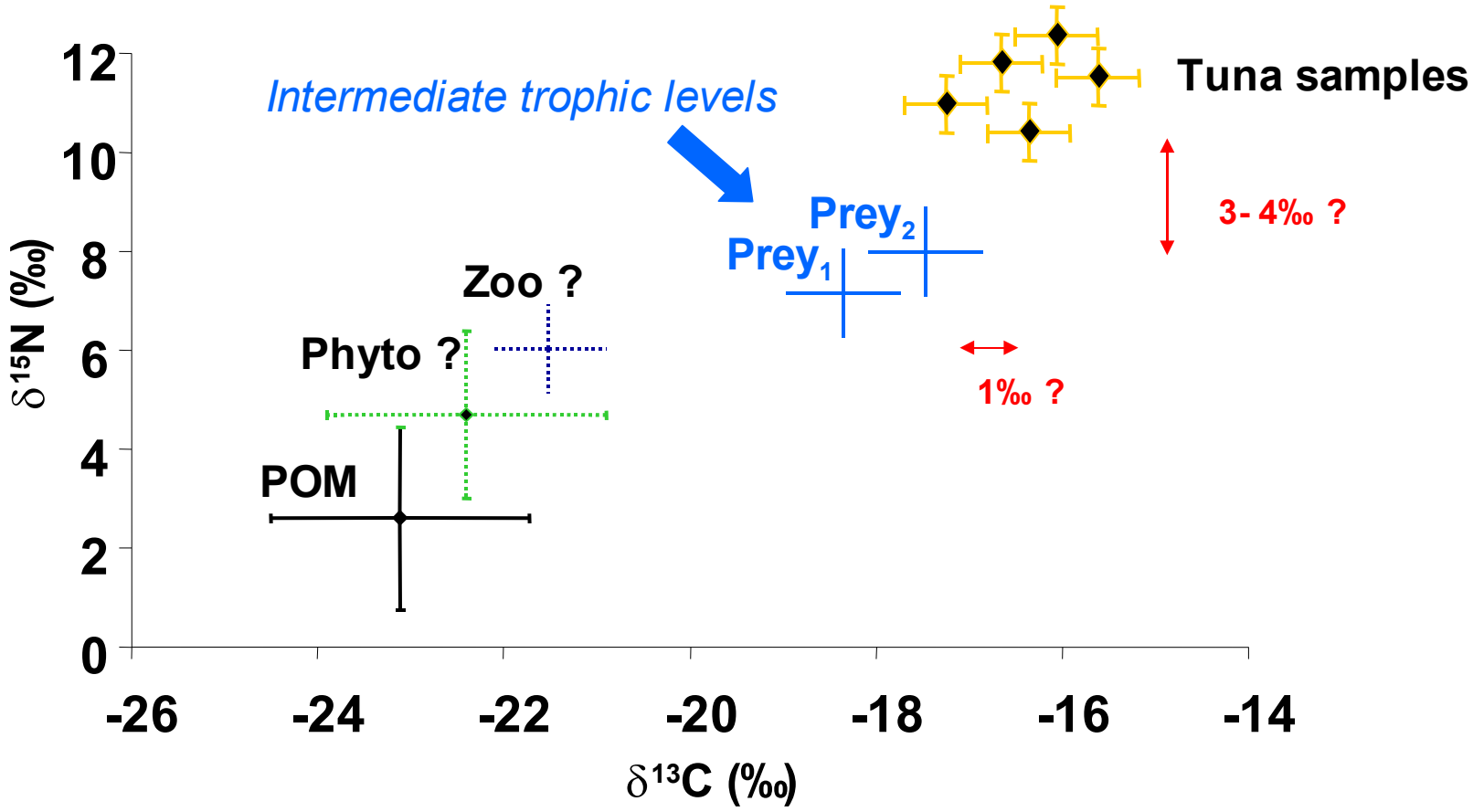
S : total no of prey in regime of both predators
aN : total no of prey in diet of predator A
bN : total no of prey in diet of predator B
an_i : no of individuals prey *i* in diet predator A
bn_i : no of individuals prey *i* in diet predator B
da , db : quadratic ratios

Feeding regimes are compared by pairs of predators
Varies from 0 (distinct feeding regimes) to 1 (identical)
Above 0.6, C is reflecting a significant overlap

4- Size Measurements

	Fresh Items	Morphometric relationships	Remainings
Crustaceans	Propod (pelagic crabs) Total length	←	Propod (pelagic crabs) Telson length
Fish	Standard length	←	Otolith length Dentary length
Cephalopods	Lower rostral length (LRL)		Lower rostral length (LRL)

5- Stable isotope ratios



- Samples of main prey, tuna and billfishes (white muscle), sharks
- POM and Phytoplankton collected but not yet analysed
- Sampling of filter feeders is underway

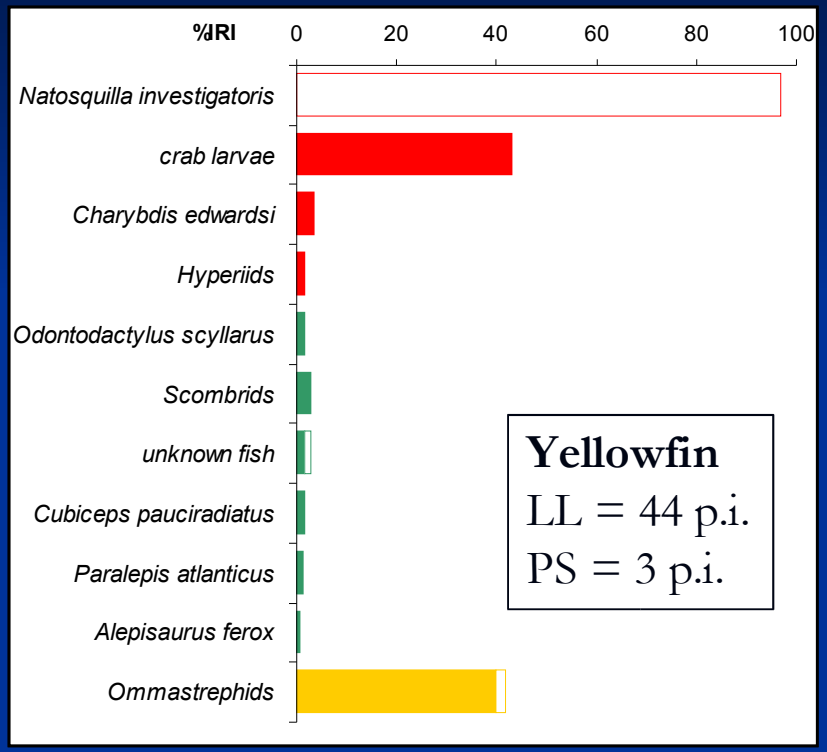
Results

1 – Prey composition and dominance studied with the IRI and Costello diagram

- YFT and BET across gears
- 4 predators with longline only

Comparison 2 pred. (YFT/BET) across gears :

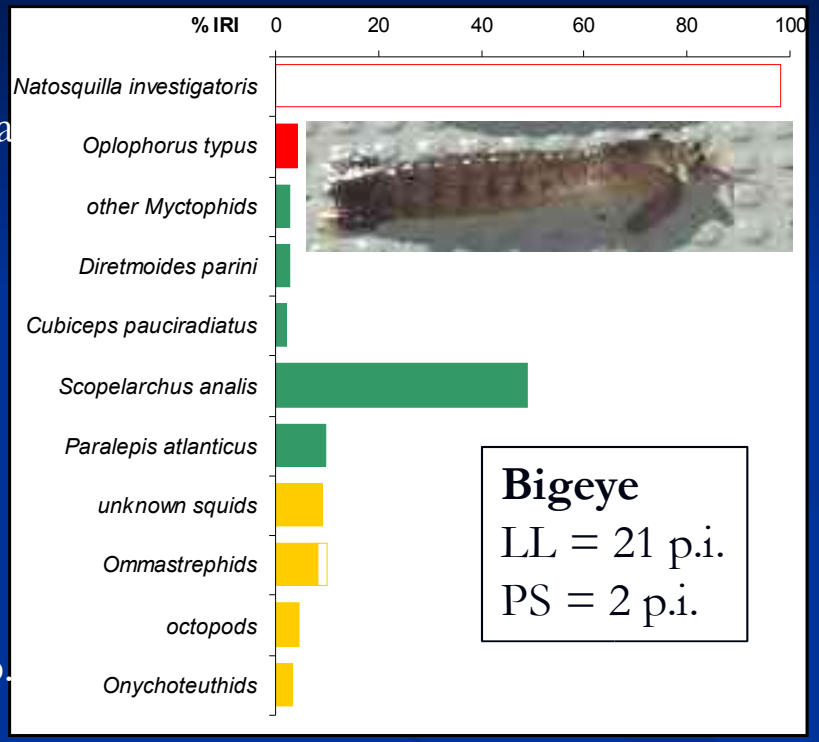
PS blank bars/LL colored bars

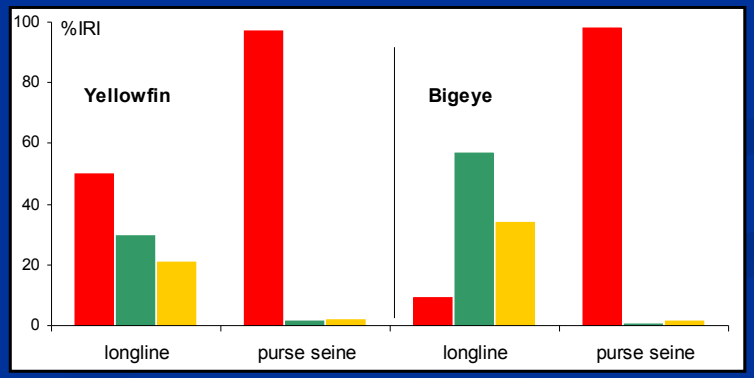


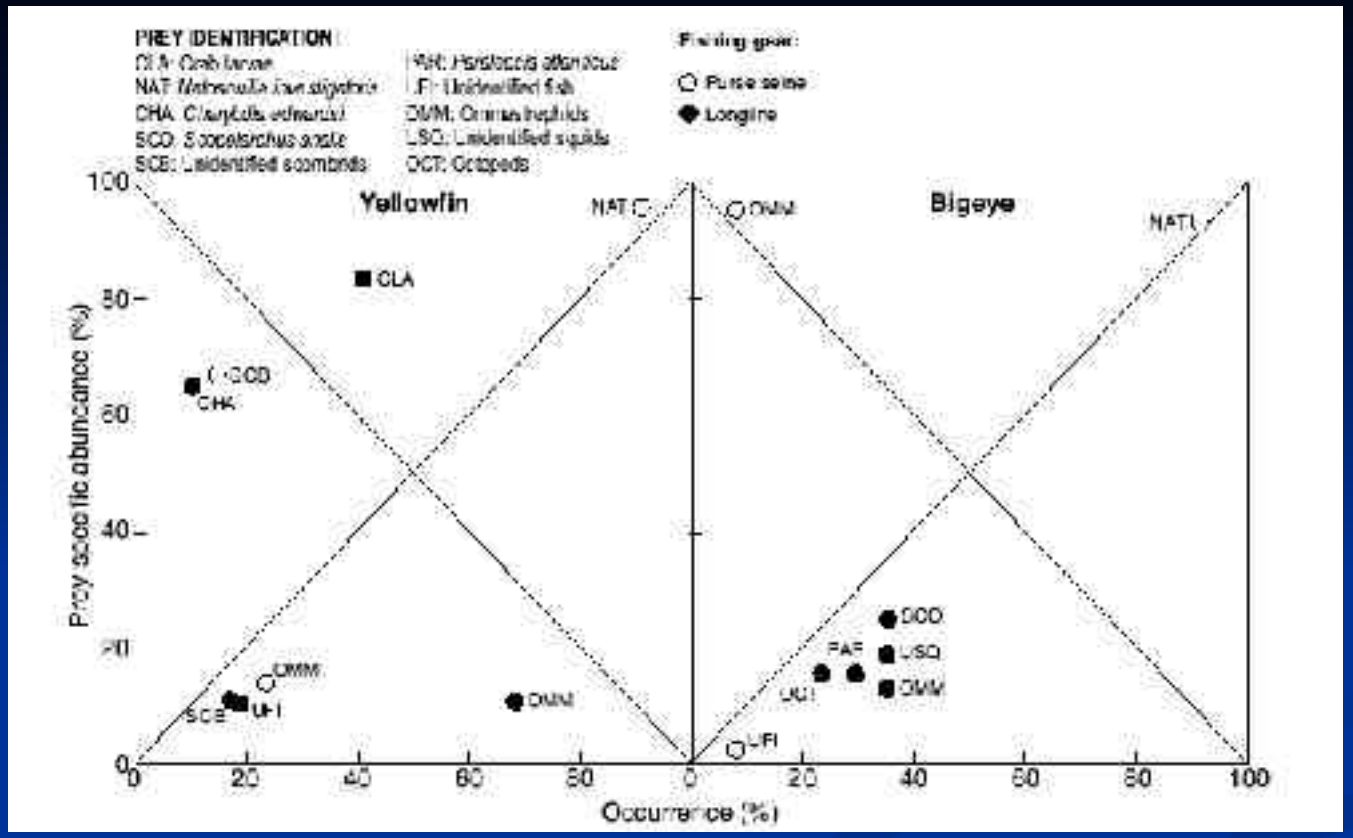
crustacea

fish

cephalop.

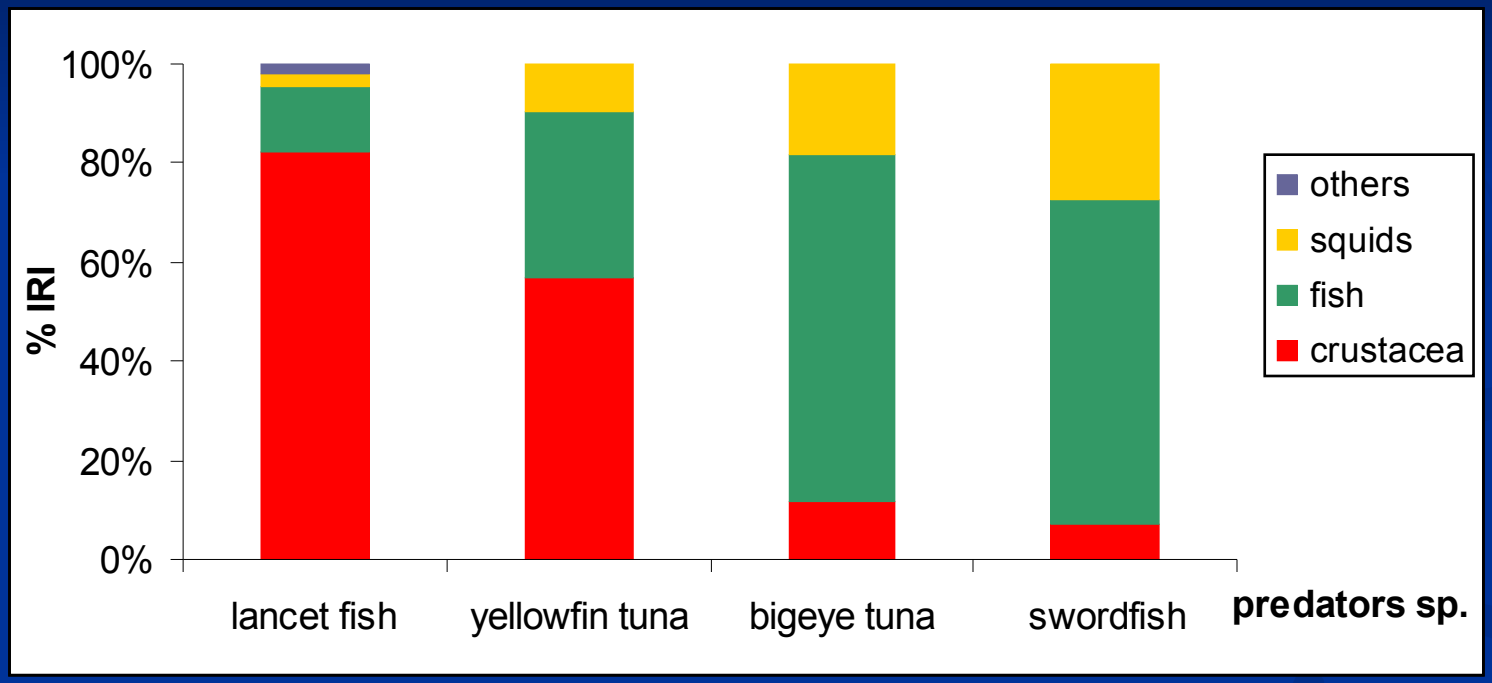






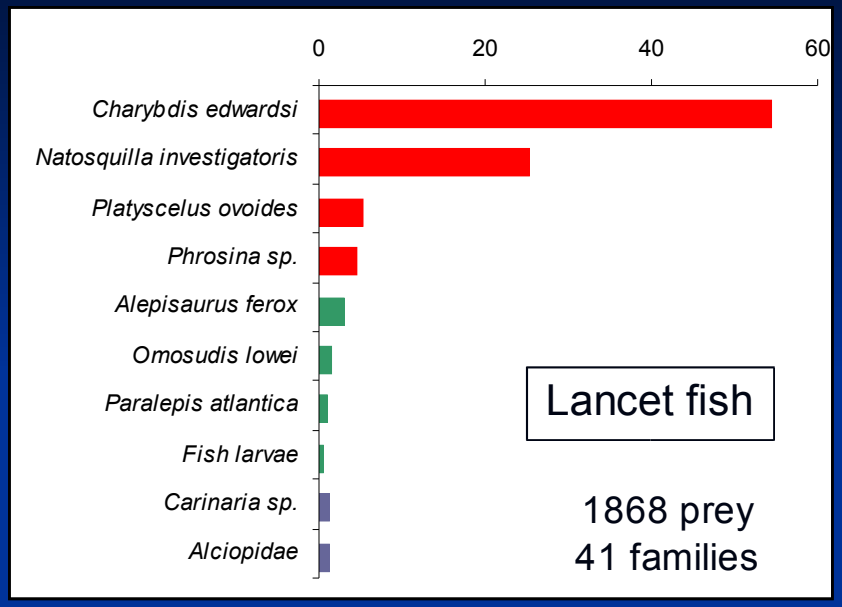
- Surface dwelling tuna (open circles)
  - Dominance of Natosquilla
  - Specialisation on Scombrids (YFT) and flying squids (BET)
- Deep dwelling tuna (black circles)
  - YFT : from generalized to specialisation (swim.crabs and crab larvae)
  - BET : generalized feeding behaviour

Comparison between 4 predators, longline gear



The proportion of each prey group (in wet mass) among the predators is consistent with the pattern depicted by the IRI

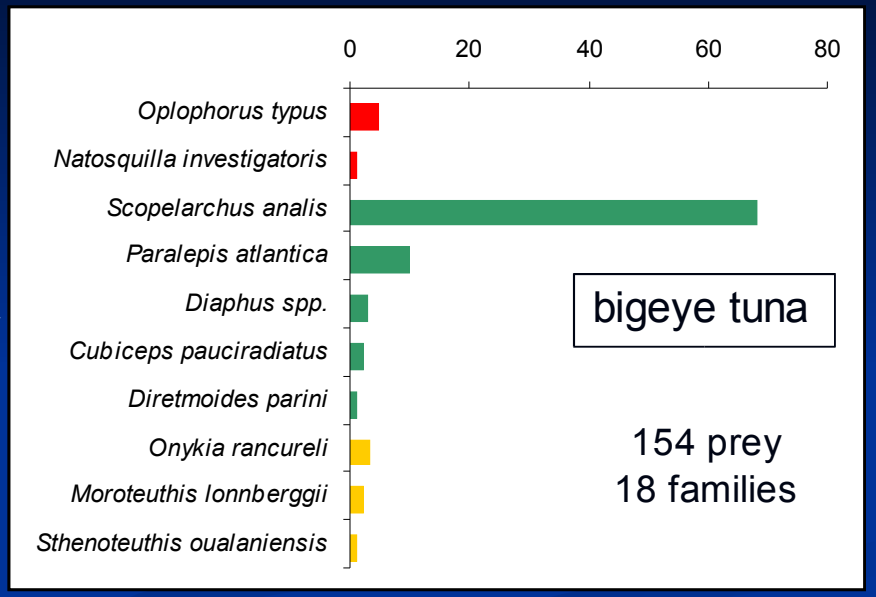
IRI by prey item and predator

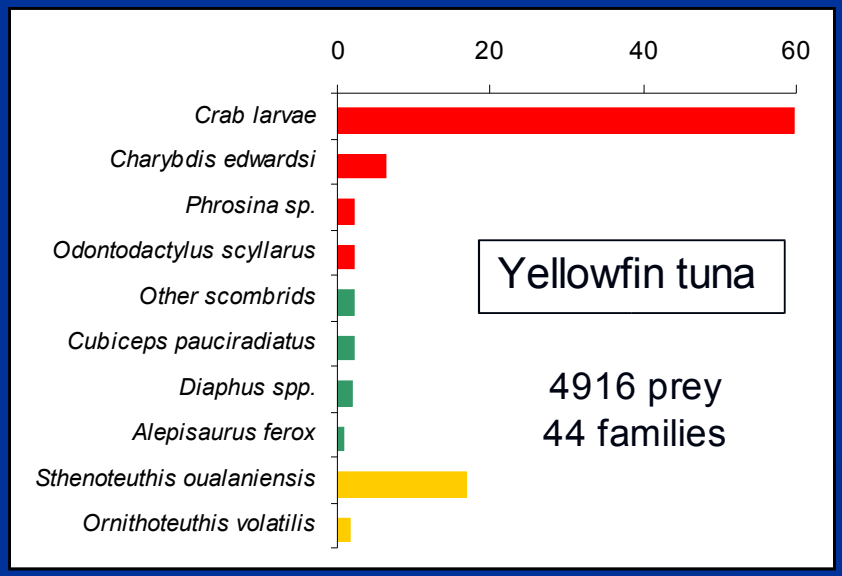


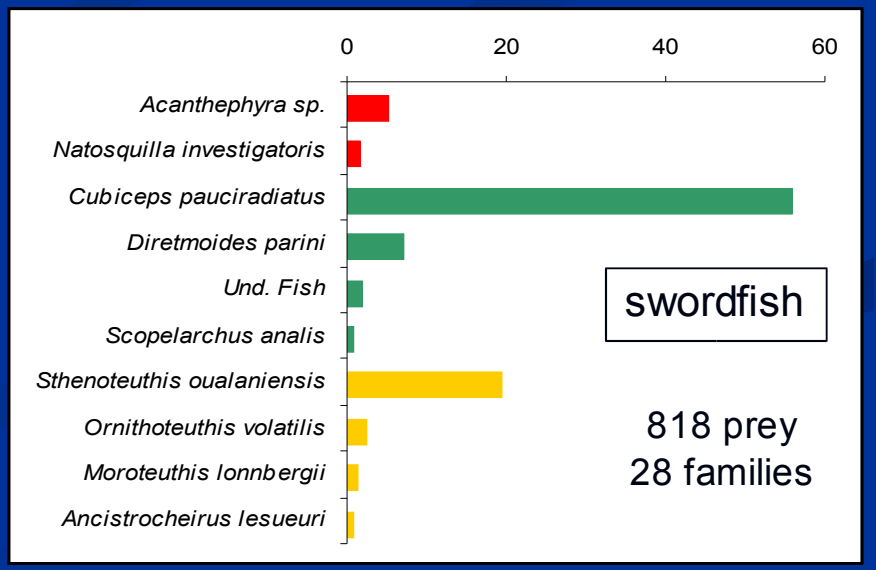
crustacea

fish

cephalop.







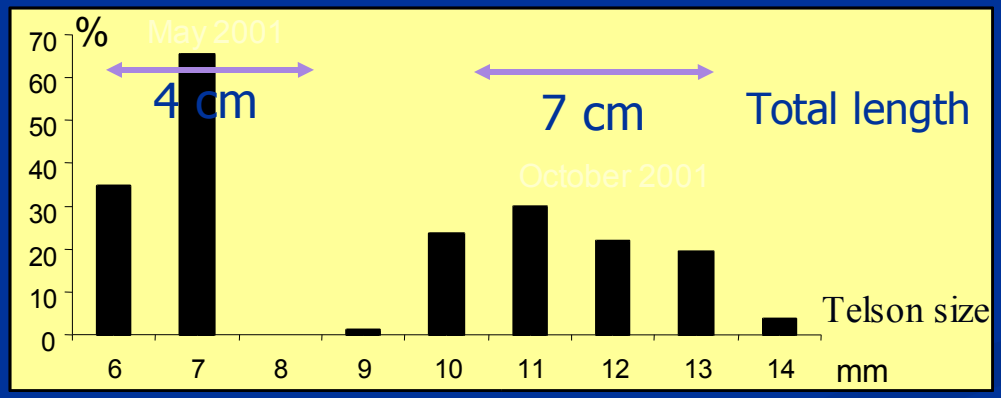
Natosquilla investigatoris
(Stomatopod)

Charybdis edwardsi
(Portunidae)

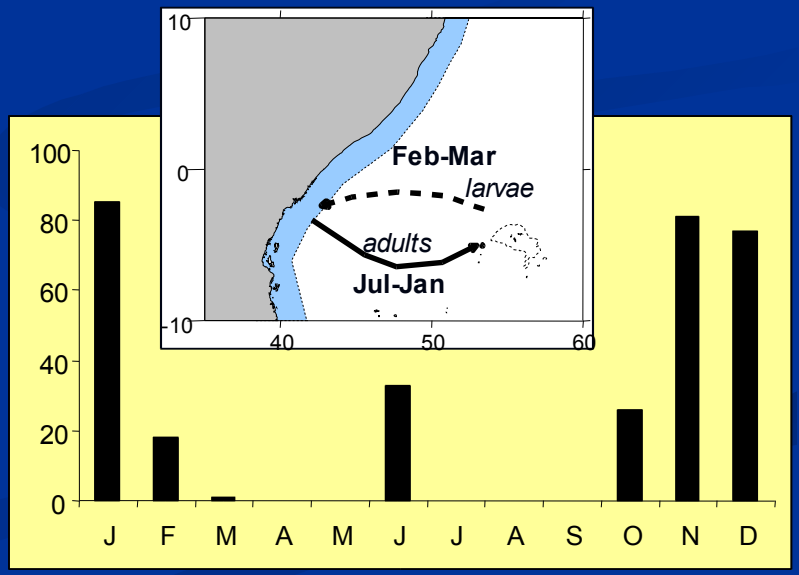
Only documented in the Indian Ocean

Demographic bursts in 1906, 1933, 1944,1967

A new episode underway since 1999 …



Swarming at the surface



Swarming in the mixed layer

Results

1 – Prey composition and dominance studied with the IRI and Costello diagram

2 - Overlap of feeding regimes

Similarity indices and cluster analysis

	YFT LL	BET LL	YFT PS	BET PS
YFT LL	1			
BET LL	0.07	1		
YFT PS	0.01	0.07	1	
BET PS	0.02	0.08	**0.99**	1

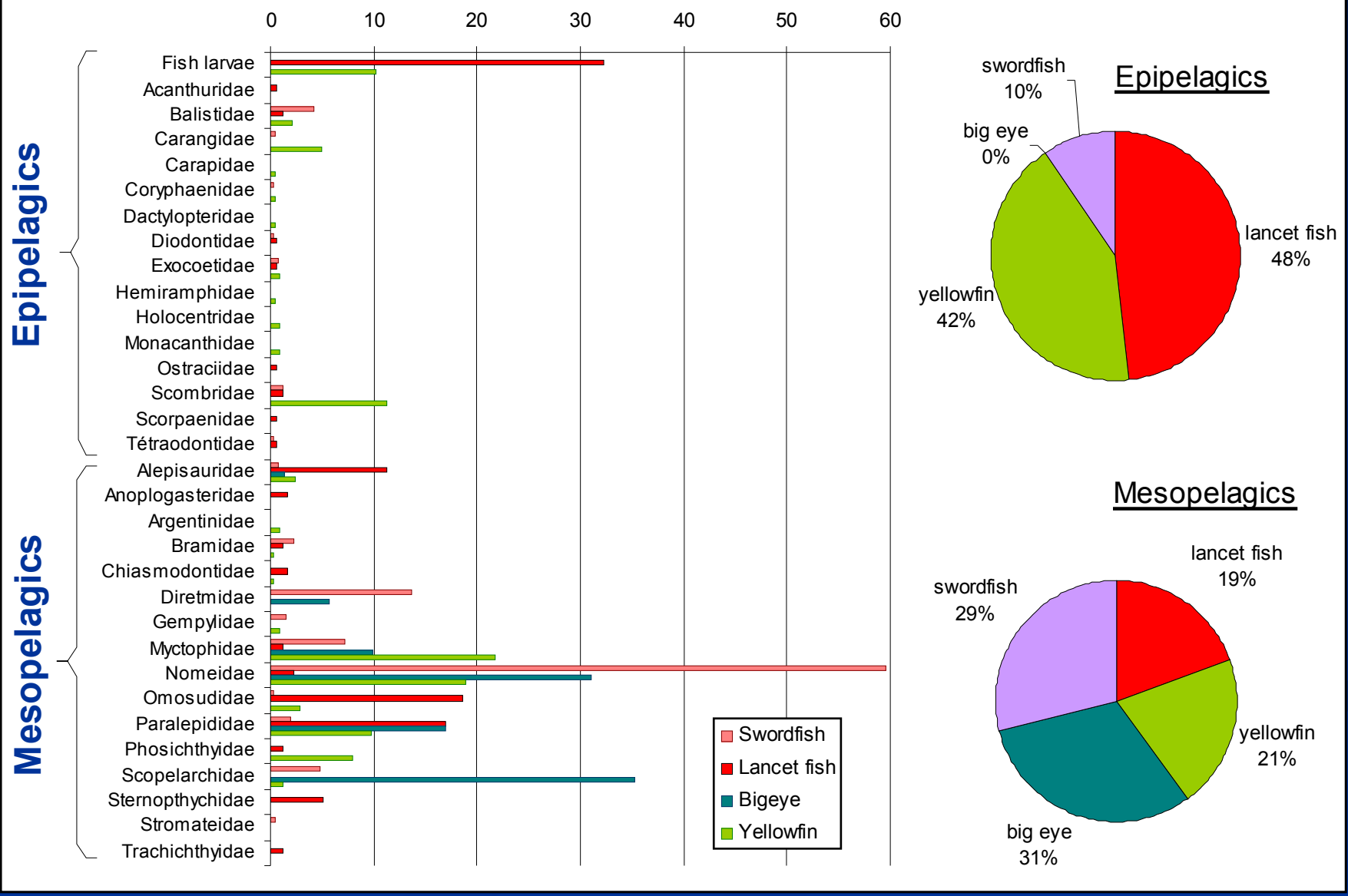
	Lancet fish	Yellowfin	Bigeye	Swordfish
Lancet fish	1			
Yellowfin	0.05	1		
Bigeye	0.14	0.07	1	
Swordfish	0.25	0.03	0.55	1

- Significant overlap within the PS
- Values close to the significant threshold between bigeye and swordfish

Cluster analysis based on IRIs

Aggregation Distance

Fish Prey Distribution



- The differences / similarities between the vertical distribution of predators are reflected in the prey composition :
  - yellowfin/lancet fish with a dominant proportion of crustaceans : epipelagic affinities
  - Bigeye/swordfish with mesopelagic fish dominating the diet

- Fish is the most diversified group among prey : 24 families reported in the YFT diet

Ocean	Area	Fish Families	Authors
Atlantic	Gulf of Guinea	20	Borodulina (1974)
Pacific	Eastern Pacific	42	Alverson (1963)
	Eastern Pacific	18	Moteki *et al.* (2001)
	Central Pacific	38	Reintjes and king (1953)
	Central Pacific	48	King and Ikehara (1956)
	Western Pacific	37	Watanabe (1958)
	Western Pacific	30	Borodulina (1982)
	Western Pacific	13	Kim *et al*. (1997)
Indian	Western Indian	23	Kornilova (1980)
	Sri Lanka	44	Maldenya (1996)
	Seychelles	24	Present study

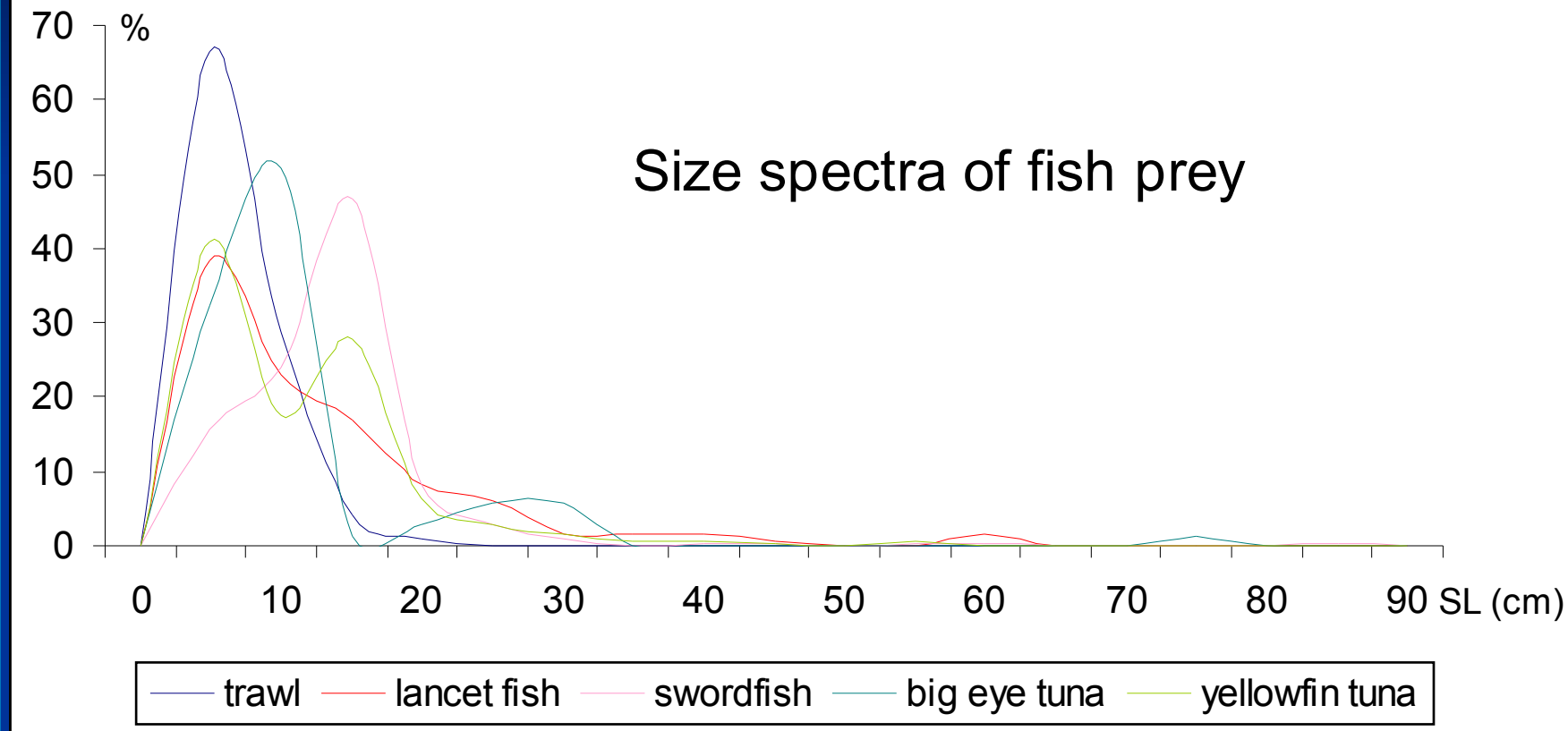
Results

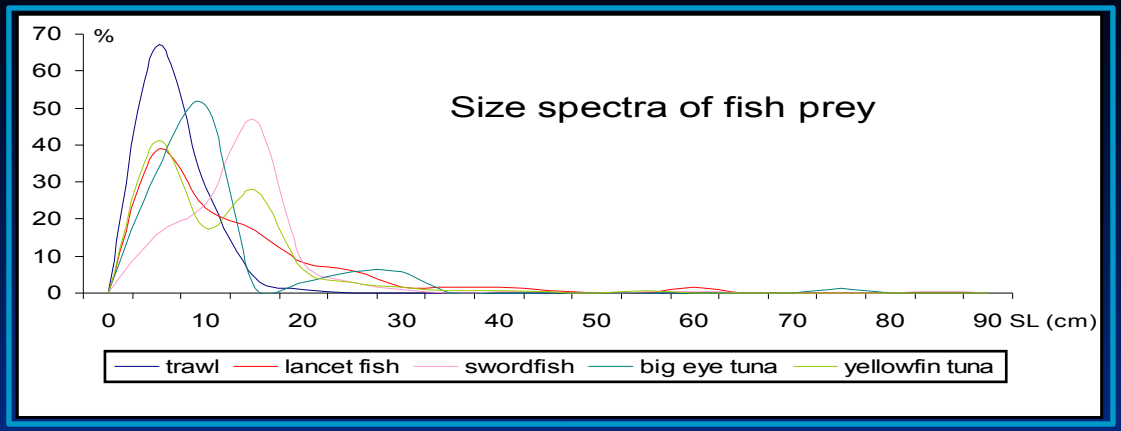
1 – Prey composition and dominance studied with the IRI

2 - Overlap of feeding regimes

3 - Size spectrum of prey

Prey sizes : trawls vs stomachs





- Swordfish and bigeye ingest bigger prey than do yellowfin and lancetfish.
- Lancetfish is a rather slow swimmer and prey upon small organisms (apart from its conspecifics).
- Swordfish has a very efficient method of capture involving the whipping action of the bill.
- The real size spectrum of prey in the water column is the overall combination of trawl collections and predator stomach contents.

Predator-prey size ratios

- Common size ratios found in FishBase : around 4 (Froese and Pauly 1998)
- In the present study, size ratios range from 10.3 to 11.8
- These high ratios can be interpreted as an optimal feeding strategy : preying upon dense swarms reduces the energetic cost of chasing
- The densest prey concentrations in the open ocean are made of small-sized individuals

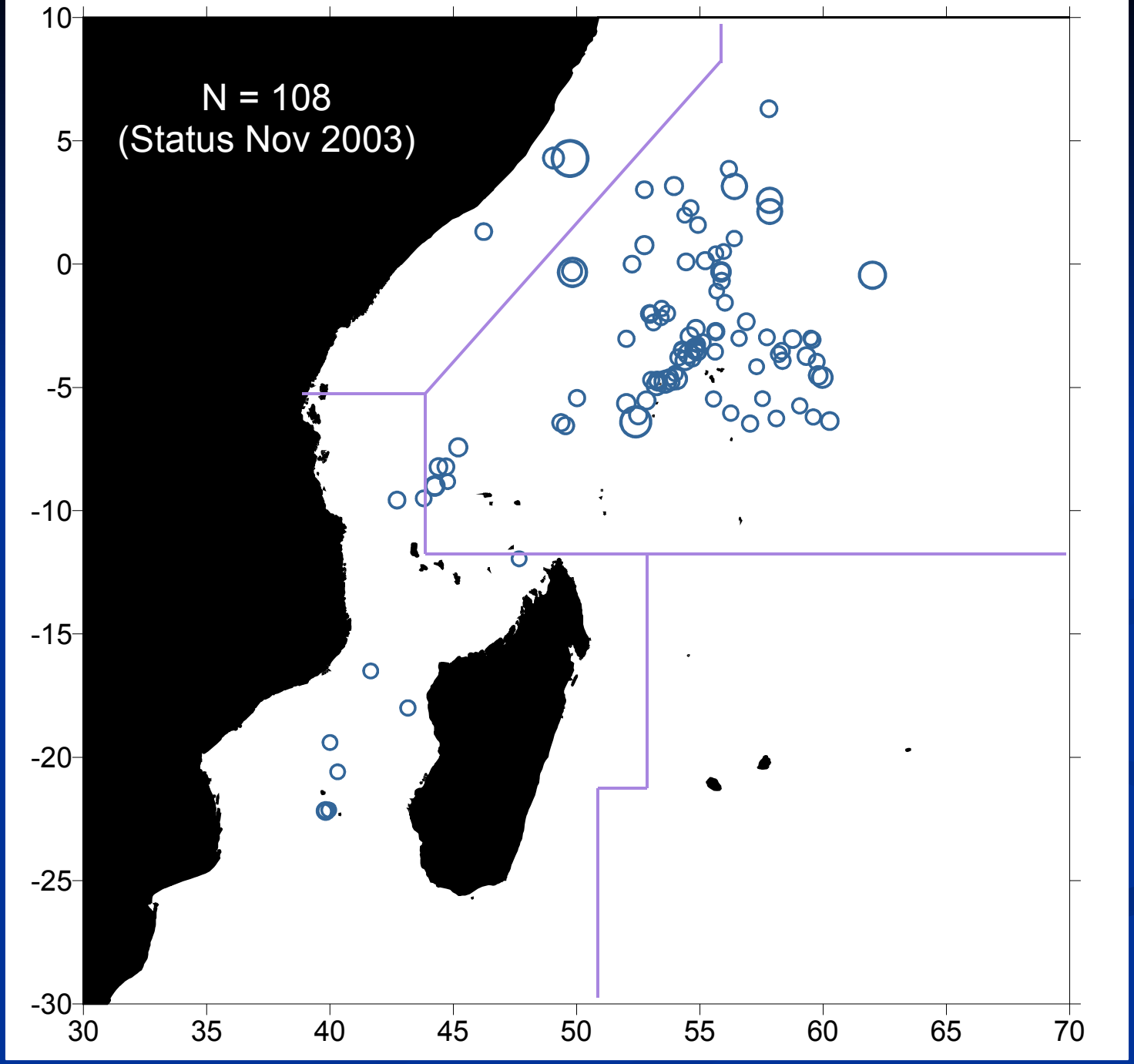
Results

1 – Prey composition and dominance studied with the IRI

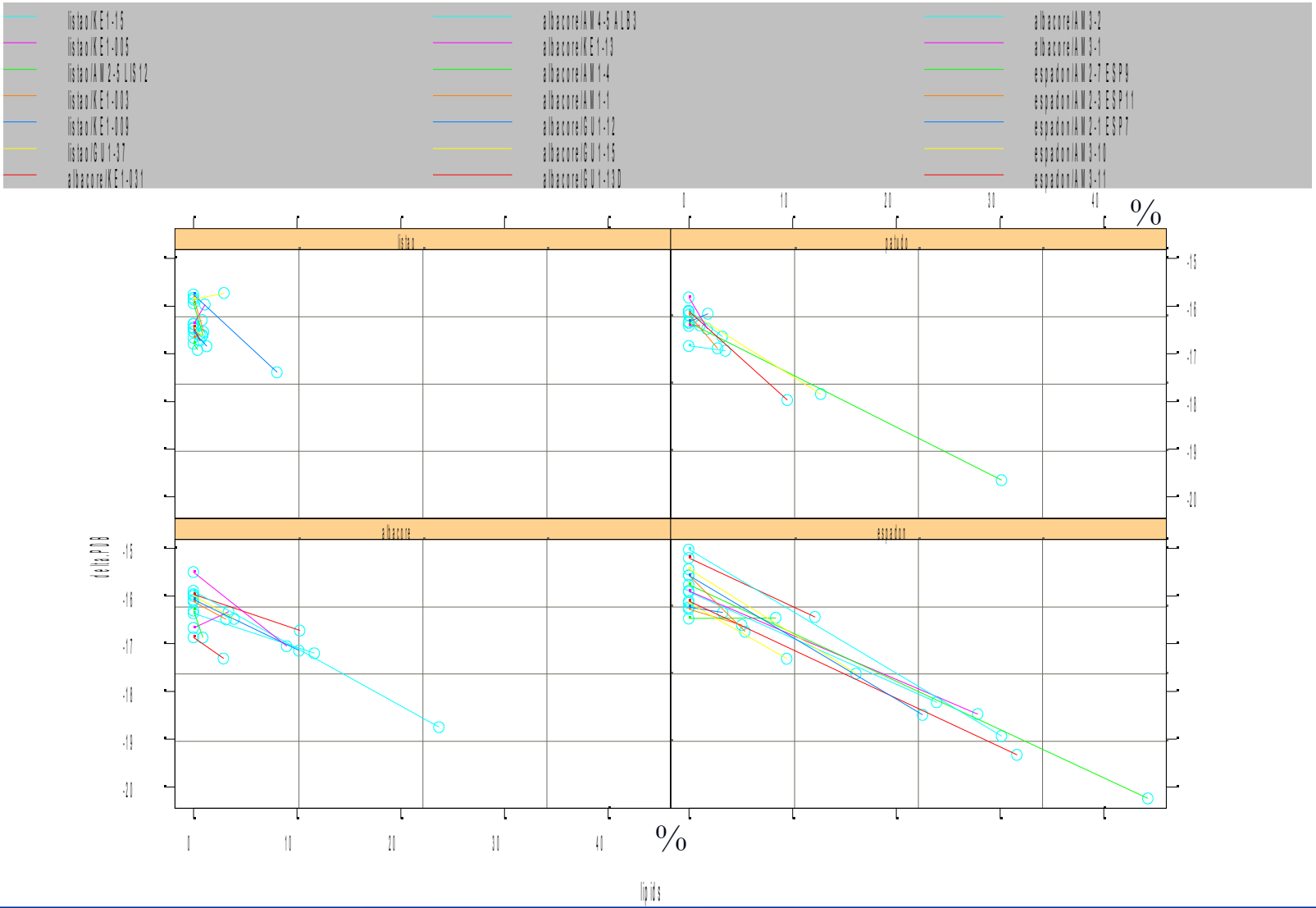
2 - Overlap of feeding regimes

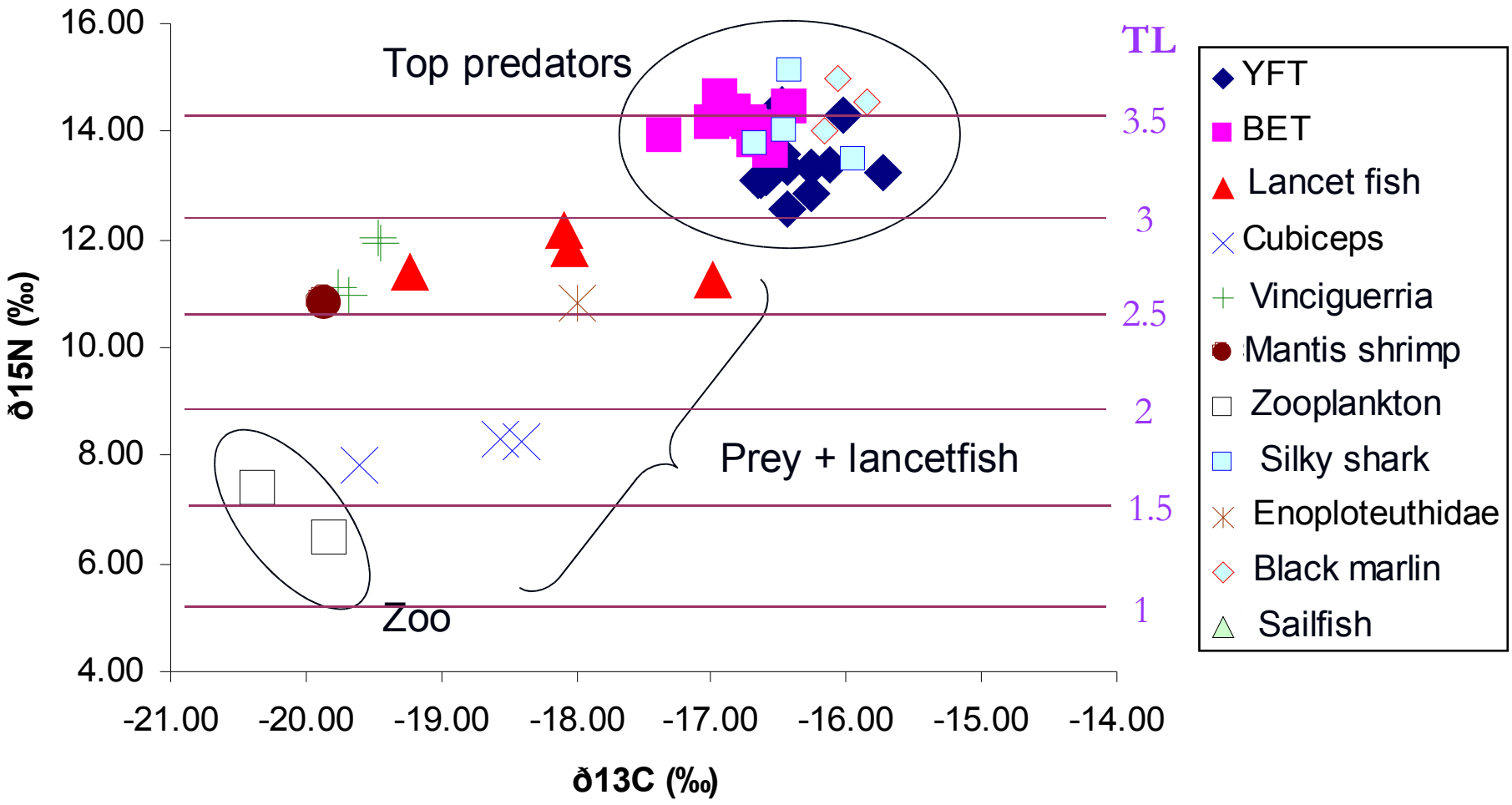
3 – Size analysis

4 – Stable Isotope ratios


N = 108
(Status Nov 2003)
10
5
0
-5
-10
-15
-20
-25
-30
30
35
40
45
50
55
60
65
70

Effect of lipid removal on $\delta^{13}C$ measurements white muscle samples





$$TL_{consumer} = 1 + (D_{consumer} - D_{POM})/\Delta TL \longrightarrow \begin{cases} D_{POM} = 5.4 \text{ (litterature)} \\ \Delta_{TL} = 3.52 \text{ (estimated)} \end{cases}$$

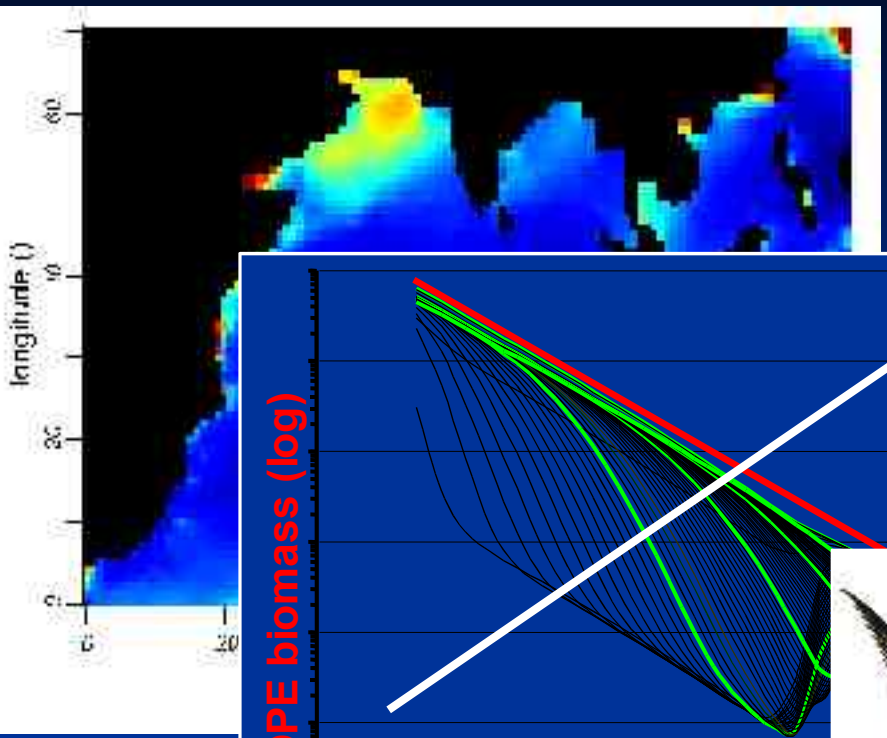
Summary

- Surface tunas exploit a very limited number of prey species : strong influence of the mantis shrimp episode
- Two functional groups utilizing different prey communities : adult yellowfin & lancetfish on one side, adult bigeye & swordfish on the other side
- The optimal feeding strategy, the high pred-prey size ratios could reveal short and simple food chains leading to apex predators in the IO equatorial ecosystem (Phytopk – Zoopk – Crustacean – Yellowfin). Needs confirmation from the isotopes.

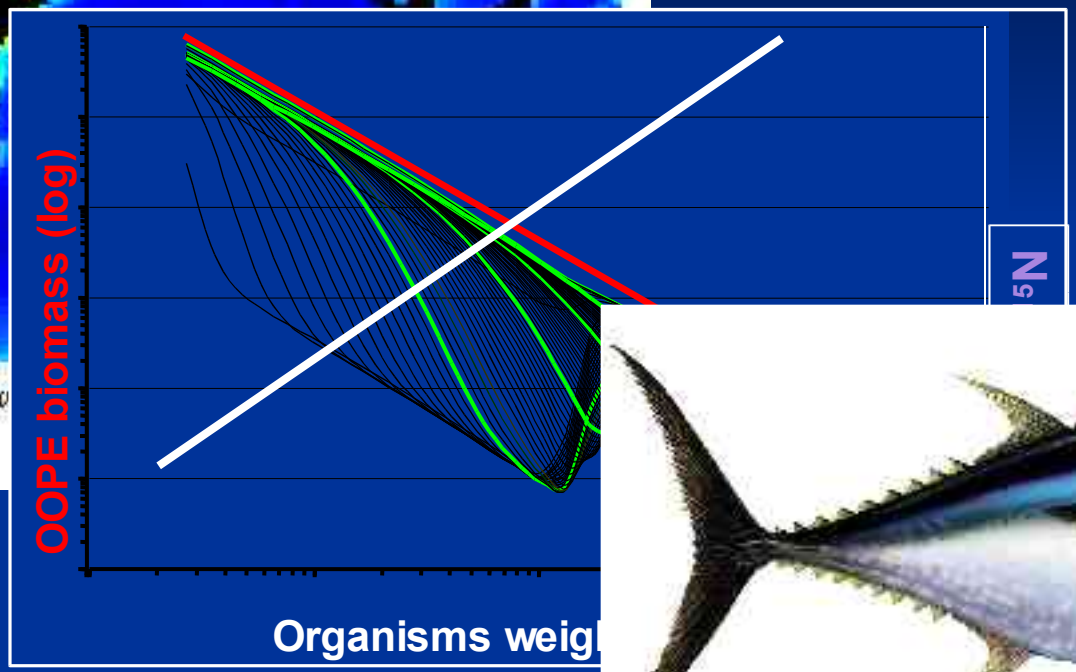
Next steps …

- Implementation of a long-term monitoring of key descriptors of the trophic pathways : tracking the shifts in maximizing the benefit/cost ratio ;
- Determine the baseline isotope signature of the ecosystem ;
- Integration of observations in a spatially explicit and size structured ecosystem model.

The APECOSM trophodynamic components



- Spatially explicit pelagic ecosystem (PE)
- Spatially explicit PE weight spectrum dynamics (by funct. Groups).



- Spatially explicit PE δ^{15}**N** weight spectrum dynamics.

- Predators sample the PE: their stomach content weight spectra (by main prey functional groups) and δ^{15}**N** dynamics are spatially explicit.

➔ The model parameters will be estimated using all the stomach content and isotope data collected