ON-GOING RESEARCH ACTIVITIES ON TROPHIC ECOLOGY OF SWORDFISH (*XIPHIAS GLADIUS*) IN THE WESTERN INDIAN OCEAN

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ABSTRACT

This paper presents the current status of data collection regarding trophic ecology studies on swordfish undertaken under the Thetis programme of the IRD. One of the main goals of this programme is to determine the predator-prey interactions in the large pelagic ecosystems, to assess the impact of the climate variability on these ecoystems, and to identify climatic and biological indicators to be used in ecosystem-based management of large pelagic resources. Although the main species group addressed in these studies are tuna, biological sampling of their competitors (like swordfish) is also made on a routine basis. The data collection for billfish consists of stomach contents and muscle samples for determining the nitrogen stable isotope composition. The results presented in this paper come from 26 stomachs taken during the first research longline trip held in August 2001 in the Seychelles region. Two sub-areas, one purely oceanic and one close to the Seychelles plateau drop-off, were defined to investigate the coastal effect on feeding activity and diet composition. The proportion of empty stomachs was relatively low (average 12%) and did not vary significantly between the sub-areas. These values are similar to other studies made in the Eastern Atlantic. However, it is still questionable whether this reflects the average feeding activity of this species, because regurgitation often occurs, and the longline gear might primarily select the hungry fish. The diet composition was dominated by fishes (whatever the sub-area), cephalopods coming second and crustacea coming third. This result is quite different from what is commonly admitted, i.e. cephalopods being the major forage category for swordfish. In our study, among the cephalopods, flying squids (Ommasprephidae) dominated, and among the fish, Cubiceps and other mesopelagics represented the major preys. Surprisingly, squids (crustacea) dominated over crustacea (squids) in the drop-off (oceanic) sub-area, when the opposite patern was expected. These differences cannot be further discussed because of the size of the sample. However, the data collection will continue until 2004 and regular re-analyses are planned during the programme. Additional information is also expected from the isotopes analyses.

INTRODUCTION

The THETIS programme of the IRD (Institut de Recherche pour le Développement) has started in 2001 for a duration of 4 years. One of the main goals of this programme is to determine the predator-preys interactions in the high seas ecosystems, to model the impact of climate variability on these ecosystems, and to define indicators that can be used as reference points for an ecosystem-based management of large pelagic resources.

The highest components of the trophic web (tunas, swordfish, marlin, sharks, wahoos, dorados) compose the main focus of the sampling, and tunas are selected as the key species for such studies. Lower components are also considered using various techniques: sea colour satellite imagery for primary productivity and acoustics coupled to pelagic trawlng to assess the forage community (mainly micro- and macro-nekton) preyed upon by apex predators.

As stated before, most of the sampling effort at sea focuses on tunas. However, we also collect samples from their competitors, such as swordfish. The purpose of the present note is to provide the current status of data collected and to briefly analyse the prey composition characterising the diet of swordfish in the Seychelles region.

METHODS

The trophic ecology approach involves different techniques, from the most traditional (analysis of stomach contents) to more sophisticated ones (stable isotope composition, lipids analysis of the muscles).

Stomach content analysis is a direct method used for studying the diet composition of the species. Oceanic vertebrates are also more efficient collectors of the pelagic fauna than the common sampling gears. Analysing stomach contents requires skilled persons for determining the prey species that are often found partly digested. The stable isotopes techniques are becoming widely used in ecology to identify the different forage sources; finally, they provide valuable information on the biological interactions in the ecosystems. The use of the nitrogen stable isotopes ratio ($^{15}N/^{14}N$) helps to locate a given fish along a trophic level scale in its ecosystem. Stable isotopes of nitrogen are enriched in an individual relative to its diet and an average 3.2 enrichment of ^{15}N ratios is suggested in the literature from one trophic level to another (Hobson and Welch, 1992; Minagawa and Wada, 1994). Finally, the analysis of fat contents in the muscles (free lipids and fatty acids) provides a quantitative condition factor of an individual that can be related with the ontogenic cycle and the habitat.

All those techniques are applied for tunas, but only stomach content analysis and nitrogen stable isotopes composition are undertaken for swordfish.

Sampling at sea is conducted from two types of vessels : commercial purse seiners and a research longliner (R/V L'Amitié, Seychelles Fishing Authority). So far, there has been four trips on purse seiners and two trips on board l'Amitié (August and October 2001). Swordfish catches by purse seiners are purely incidental, and none has been recorded during the four trips. On the other hand, it is easy to target swordfish with longline, especially during night sets. 26 swordfish have been caught during the August 2001 trip and 14 during the October trip. Stomachs have been collected for all these fish, and 6 muscle samples taken in the anterior dorsal muscle for isotopes analyses. For each sample, size (LCOF, LMF and LPA), sex, maturity, indicative fullness index of the stomach and time of biting (when available with hook timers) are recorded. The stomachs are put in a plastic bag (with identification number) and stored at –20°C. The muscle samples (approx. 2 cm^3) are put in a small plastic container and stored at –20°C.

At the laboratory, stomachs are defrost 24h before the analysis which is made in three steps:

1) stomach with contents on one side, and contents only on the other side, are weighted. Then the content is sorted by large categories (fish, molluscs, crustacea). The weight of each category is noted.

2) the different items constituting the groups are sorted and counted. For each items remarkable organs are used to determine the number of preys in the stomach. For fish the number of mandibles, or parasphenoids or the maximum number of either left or right otolith was assumed to reflect the total number of fish prey in the stomach. Similarly the greatest number of either upper or lower beaks is used as an indication of the number of cephalopods prey in the stomach. For crustacea, telsons or pleopods are used.

3) different items are determined to the lowest taxum. The reconstituted weight of the food meal will be done by calculating regressions relating dimensions of remarkable organs to the weight of the items. For example, total fish length and weight are related to otolith, mandibles or parasphenoids sizes, and squid weight and dorsal mantle length to beak dimension.

In this short presentation of on-going work, we used the results obtained at the end of the second step. Two derived variables were calculated:

quantitative stomach fullness index (QSF)

QSF = Wc / Ws , where Wc is the weight of the stomach content only, and Ws the weight of the stomach including the content

Index of Relative importance (IRI) (Pinkas et al., 1971)

IRI = (N% + W%) x F% , where N% is the relative proportion in numbers, W% the relative proportion in weight, F% the relative frequency occurrence of a given prey group among all stomachs with food.

RESULTS

A summary of the location and biological characteristics of all billfishes caught during the two trips at sea (AMITIE I and II) are presented in Table 1. Swordfish is the more abundant species sampled, and sailfish (*Istiophorus platypterus*) and black marlin (*Makaira indica*) come second and third. The size range of swordfish (LCOF) is 56-145 cm, with a mode at 90-110 cm (figure 1). The catches were all made in the northern Seychelles region (between 0° and 4°S). The location of sets (with number of swordfish caught) is given in figure 2.

The following results will only concern the first trip, since the analysis of samples collected in October has not yet started. From an original number of 26 stomachs, one was damaged and the sole content was collected. Therefore, it was not possible to calculate the QSF for one individual. However, the 26 contents were analysed for the prey characteristics.

Stomach fullness analysis

The overall distribution of stomach fullness indices exhibits a low proportion –12%- of empty stomachs. The dominant status is in the range 1-25% fullness (figure 3a). According to the geographic distribution of catches, we defined two sub-areas, an oceanic area (2 sets at 2°S-3°S) and an area situated close to the Seychelles plateau (namely drop-off area) amounting 4 sets located at 3°S-4°S.

The fullness indices of the two sub-areas are displayed in figure 3 (b-c). Although a larger proportion of 25-50% stomach fullness is found in the oceanic area, the variances do not differ significantly as summarised in the following table :

Fullness index	Oceanic area	Drop-off area
Mean	19.14	15.02
Variance	217.38	379.33
N	7	18
F ratio	1.74502272	
	not significant	

Stomach content analysis

In the limited sample studied, the diet of swordfish is dominated by fish, in weight, number and occurrence (figure 4). Then follow cephalopods and crustacea.

Crustacea were only shrimps; three species have been discriminated but not yet determined. Among the cephalopods, the Ommastrephidae are the dominant family, but three other families of squids and 1 family of octopus need to be determined. The dominant fishes in the diet are mesopelagic : *Cubiceps pauciradiatus* and two Diretmidae (*Diretmoides parini* and *Diretmus argenteus*). Apart from cephalopods, the occurrence in both sub-areas is very similar.

According to the previous results, the relative importance is dominated by fish, with similar values in both sub-areas. The importance of the two other forage categories are opposite from drop-off to ocean : crustacea dominates in the oceanic area, whilst cephalopods dominate in the drop-off area (figure 5).

DISCUSSION

The results presented in this short note must be seen as provisional, due to the small number of stomachs analysed (26). However, they can be reviewed in perspective with the results found in the literature.

The stomach fullness index is still questionable because regurgitation regularly occurs. The proportion of empty stomachs in this study(12%) is similar to those found by other authors : 10% by Stillwell and Kohler (1985), 16% by Hernandéz-Garcia (1995). However, they all appear low compared to the 36% calculated by Velasco and Quintans (1999). These authors even suggest that emptyness calculated from longline data sets is always underestimated because they consider that baited hooks attract primarily hungry fish.

Regarding the diet composition, cephalopods often appear as the dominant forage group in the literature, followed by fish. Crustacea compose the lower fraction of the diet. In our data set, fish is always dominant over cephalopods and crustacea. However, Ommastrephidae (flying squids) are the dominant squid species in the area surveyed, as already noted in the east Atlantic ocean (Guerra et al 1993, Hernandéz-Garcia 1995, Velasco and Quintans 1999). Among the fish, Cubiceps were the more abundant genus in our data set; this same genus still had a great importance in the diet of swordfish in the Atlantic (Velasco and Quintans 1999).

Swordfish is known to have an opportunistic feeding behaviour. Geographical differences have already been noted by several authors, but these differences seem to be due to the vicinity of coasts or shelves more than any other type of stratification (by latitude or longitude). We tried to investigate this property in discriminating between oceanic sets and sets made close to the drop-off of the Seychelles plateau. There is no difference for fish, but we obtained outstanding results for cephalopods and crustacea. We could have expected a greater importance of squids in the oceanic waters compared to crustacea (shrimps), but the opposite was observed. A inverse importance relationship between cephalopods and crustacea was obtained in the drop-off zone.

CONCLUSION

As mentioned above, nothing conclusive can be brought up in this paper due to the small size of the sample used. The sampling at sea is just beginning and this first analysis enables to set up the scene. We can expect valuable information from the stable nitrogen isotopes analyses. The data collection of stomachs and muscle tissue will be continued until 2004, with several trips each year. In order to assess the time of hooking, hook timers will soon be deployed in significant numbers on the 500-hooks longline handled by the research vessel. We have good hope that significant results will emerge from these various sources of data, and will provide better understanding of the relationships between swordfish and the other components of the pelagic ecosystem.

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Table 1 – Location and characteristics of billfish catches during the two longline research cruises around Seychelles (August and October 2001)

Cruise	longline set	date	latitude	longitude	species	size (cm)	sex	Fullness index	hooking time
Amitié I	I	8/14/2001	2°35'S	53°05' E	*Xiphias gladius*	86	F	2	und.
	I	8/14/2001	2°35'S	53°05' E	*Xiphias gladius*	102	F	2	und.
	I	8/14/2001	2°35'S	53°05' E	*Xiphias gladius*	86	M	1	und.
	I	8/14/2001	2°35'S	53°05' E	*Xiphias gladius*	88	F	2	und.
	I	8/14/2001	2°35'S	53°05' E	*Xiphias gladius*	68	F	2	und.
	II	8/15/2001	2°11' S	53°41' E	*Xiphias gladius*	90	F	9	und.
	II	8/15/2001	2°11' S	53°41' E	*Xiphias gladius*	114	M	2	und.
	II	8/15/2001	2°11' S	53°41' E	*Xiphias gladius*	117	M	2	und.
	IV	8/17/2001	2°59' S	55°11' E	*Xiphias gladius*	114	9	2	und.
	IV	8/17/2001	2°59' S	55°11' E	*Xiphias gladius*	89	F	2	und.
	V	8/19/2001	3°05' S	54°50' E	*Xiphias gladius*	56	3	1	und.
	VI	8/20/2001	3°25' S	54°30' E	*Xiphias gladius*	91	imm.	1	und.
	VI	8/20/2001	3°25' S	54°30' E	*Xiphias gladius*	85	F	2	und.
	VI	8/20/2001	3°25' S	54°30' E	*Xiphias gladius*	65	F	2	und.
	VI	8/20/2001	3°25' S	54°30' E	*Xiphias gladius*	83	M	2	und.
	VI	8/20/2001	3°25' S	54°30' E	*Xiphias gladius*	120	M	2	und.
	VIII	8/22/2001	3°46' E	54°25' E	*Xiphias gladius*	84	F	2	und.
	VIII	8/22/2001	3°46' E	54°25' E	*Xiphias gladius*	99	M	2	und.
	VIII	8/22/2001	3°46' E	54°25' E	*Xiphias gladius*	82	M	1	und.
	VIII	8/22/2001	3°46' E	54°25' E	*Xiphias gladius*	86	F	1	und.
	VIII	8/22/2001	3°46' E	54°25' E	*Xiphias gladius*	83	F	2	und.
	VIII	8/22/2001	3°46' E	54°25' E	*Xiphias gladius*	80	M	2	und.
	VIII	8/22/2001	3°46' E	54°25' E	*Xiphias gladius*	75	imm.	2	und.
	VIII	8/22/2001	3°46' E	54°25' E	*Xiphias gladius*	83	M	2	und.
	VIII	8/22/2001	3°46' E	54°25' E	*Xiphias gladius*	89	M	2	und.
	VIII	8/22/2001	3°46' E	54°25' E	*Xiphias gladius*	85	M	3	und.
Amitié II	I	10/18/2001	0°02' S	54°27' E	*Xiphias gladius*	95	M	9	und.
	I	10/18/2001	0°02' S	54°27' E	*Xiphias gladius*	93	M		und.
	I	10/18/2001	0°02' S	54°27' E	*Xiphias gladius*	83	imm		und.
	I	10/18/2001	0°02' S	54°27' E	*Xiphias gladius*	122	M	9	und.
	I	10/18/2001	0°02' S	54°27' E	*Xiphias gladius*	116	M		und.
	I	10/18/2001	0°02' S	54°27' E	*Xiphias gladius*	95	F		und.
	I	10/18/2001	0°02' S	54°27' E	*Xiphias gladius*	102	F		und.
	I	10/18/2001	0°02' S	54°27' E	*Xiphias gladius*	91	F	9	0:55
	II	18 and 19/10/01	0°09' S	55°05' E	*Xiphias gladius*	71	imm		und.
	II	19 and 19/10/01	0°09' S	55°05' E	*Xiphias gladius*	145	F		21:35
	III	10/20/2001	0°44' S	55°42' E	*Xiphias gladius*	80	F		day
	III	10/21/2001	0°44' S	55°42' E	*Makaira indica*	210	M	4	14:05
	IV	10/22/2001	2°39' S	55°32' E	*Makaira indica*	248	F	9	day
	V	10/23/2001	3°04' S	54°44' E	*Istiophorus platypterus*	154	F	3	und.
	V	10/24/2001	3°04' S	54°44' E	*Istiophorus platypterus*	171	M	3	und.
	VI	10/24/2001	2°58' S	54°44' E	*Makaira indica*	196	F	3	und.
	VI	10/25/2001	2°58' S	54°44' E	*Istiophorus platypterus*	179	M	2	day
	VII	10/25/2001	3°37' S	55°23' E	*Istiophorus platypterus*	201	F	3	und.
	VII	10/26/2001	3°37' S	55°23' E	*Xiphias gladius*	80	F	4	und.
	VII	10/27/2001	3°37' S	55°23' E	*Xiphias gladius*	86	F	4	und.
	VII	10/28/2001	3°37' S	55°23' E	*Xiphias gladius*	88	M	3	und.
	VII	10/29/2001	3°37' S	55°23' E	*Istiophorus platypterus*	202	M		12:54
	VII	10/30/2001	3°37' S	55°23' E	*Istiophorus platypterus*	91	M	3	und.
	VII	10/31/2001	3°37' S	55°23' E	*Istiophorus platypterus*	206	M	3	und.

Notes : **sex** **Filling index** **Size** **hooking time**

Table 2 – Prey composition of the diet of swordfish in the area surveyed (North Seychelles)

Prey category	Prey group	Families	Species	occurrence drop-off	occurrence oceanic	occurrence total
Crustacea	shrimps					
			A	4	5	9
			B	1	2	3
			C		1	1
Cephalopods	squids	Ommastrephidae		8	1	9
		A		2	1	2
		B		4		4
		C		5		5
	octopuses	A		1		1
Fish	fish	Exocoetidae				
			Exocoetus volitans	1	1	2
		Nomeidae				
			Cubiceps pauciradiatus	9	5	14
		Diretmidae				
			Diretmoides parini	3	4	7
			Diretmus argenteus	1	1	2
		Scopelarchidae		1	1	2
		Myctophidae				
			Lampadena luminosa	1		1
		Undetermined		3	2	5

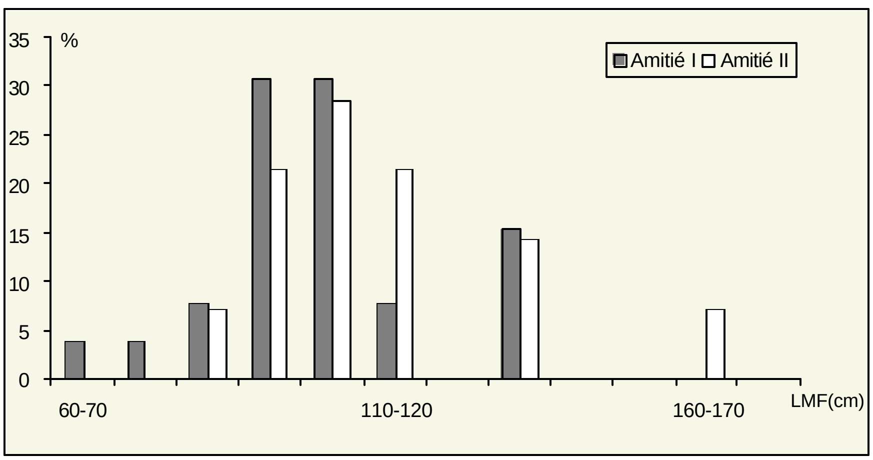
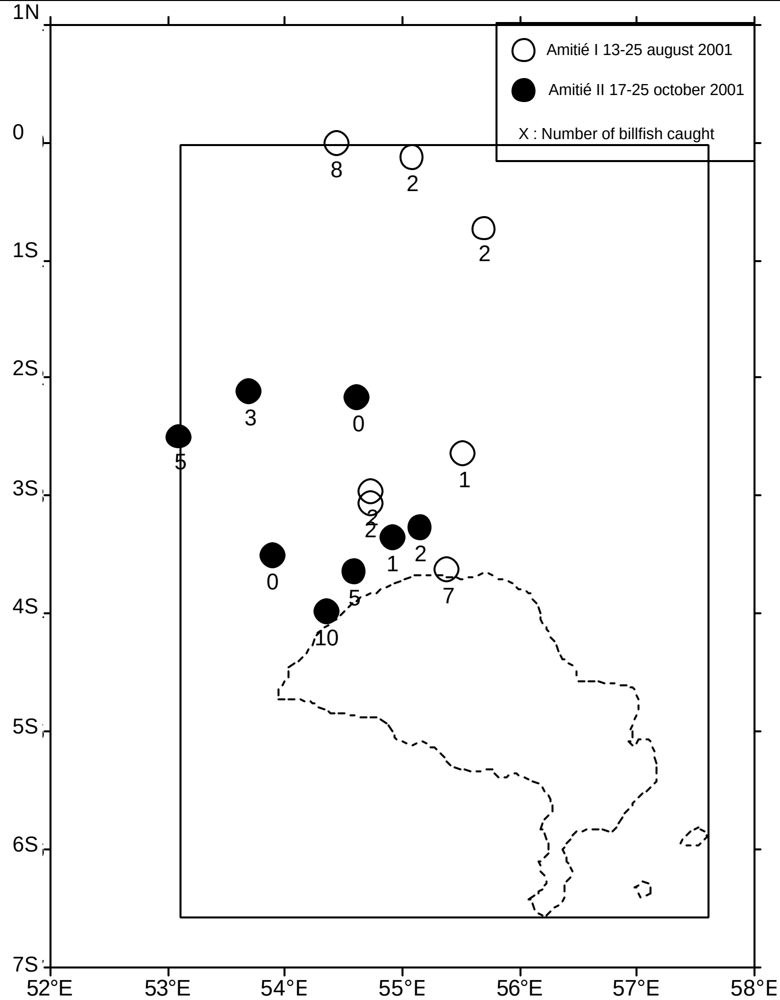


Figure 1 – Size distribution of swordfish caught during the two longline trips

Figure 2 – Location of longline sets with number of swordfish caught



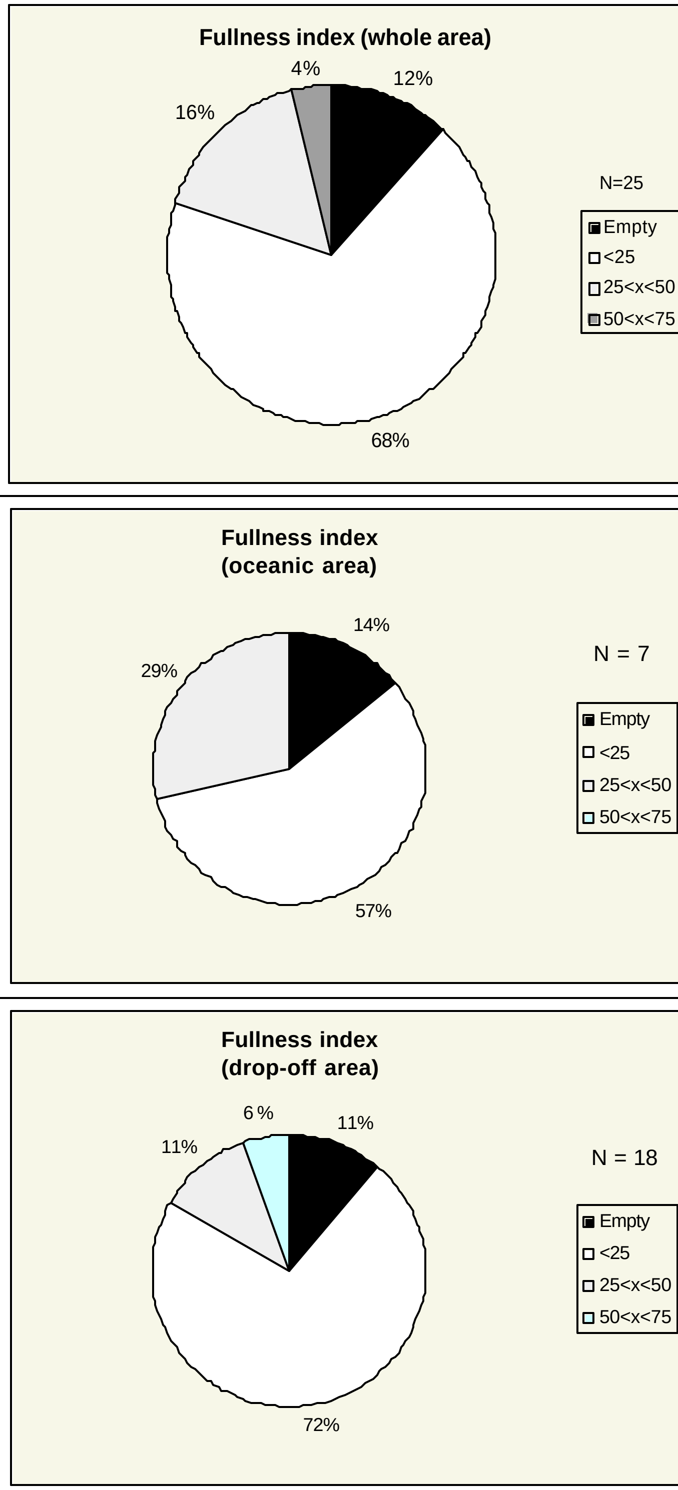


Figure 3 – Indices of stomach fullness in the whole area, and in the two sub-areas (oceanic and Seychelles plateau drop-off)

Forage category	weight	number	occurrence
Crustacea	9.74	20.17	43.48
Cephalopods	25.01	16.81	60.87
Fish	65.25	63.03	91.30

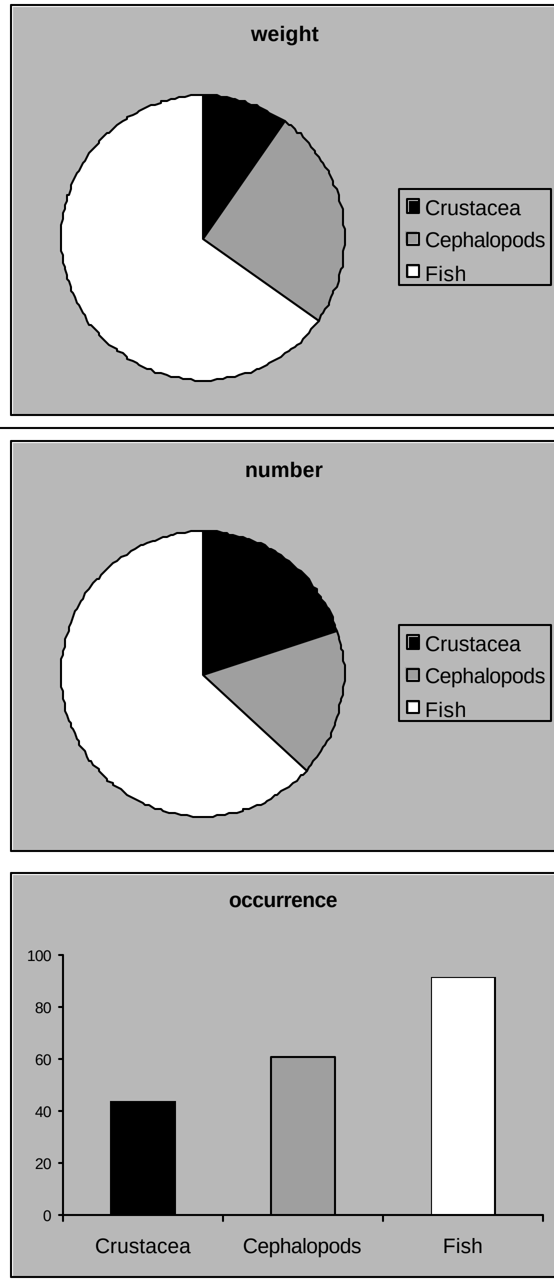


Figure 4 – Comparison of the dietary importance of the three forage categories in swordfish stomachs

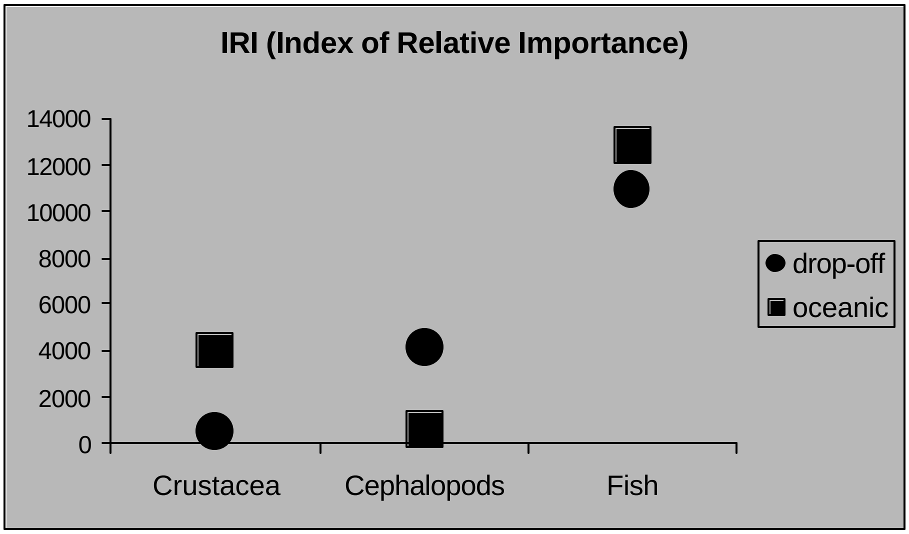


Figure 5 – Comparison of the Index of Relative Importance in the two sub-areas