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**COLONIZATION OF THE F/V *CALÉDONIE TOHO 2* WRECK BY A
REEF-FISH ASSEMBLAGE NEAR NOUMÉA (NEW CALEDONIA)**

BY

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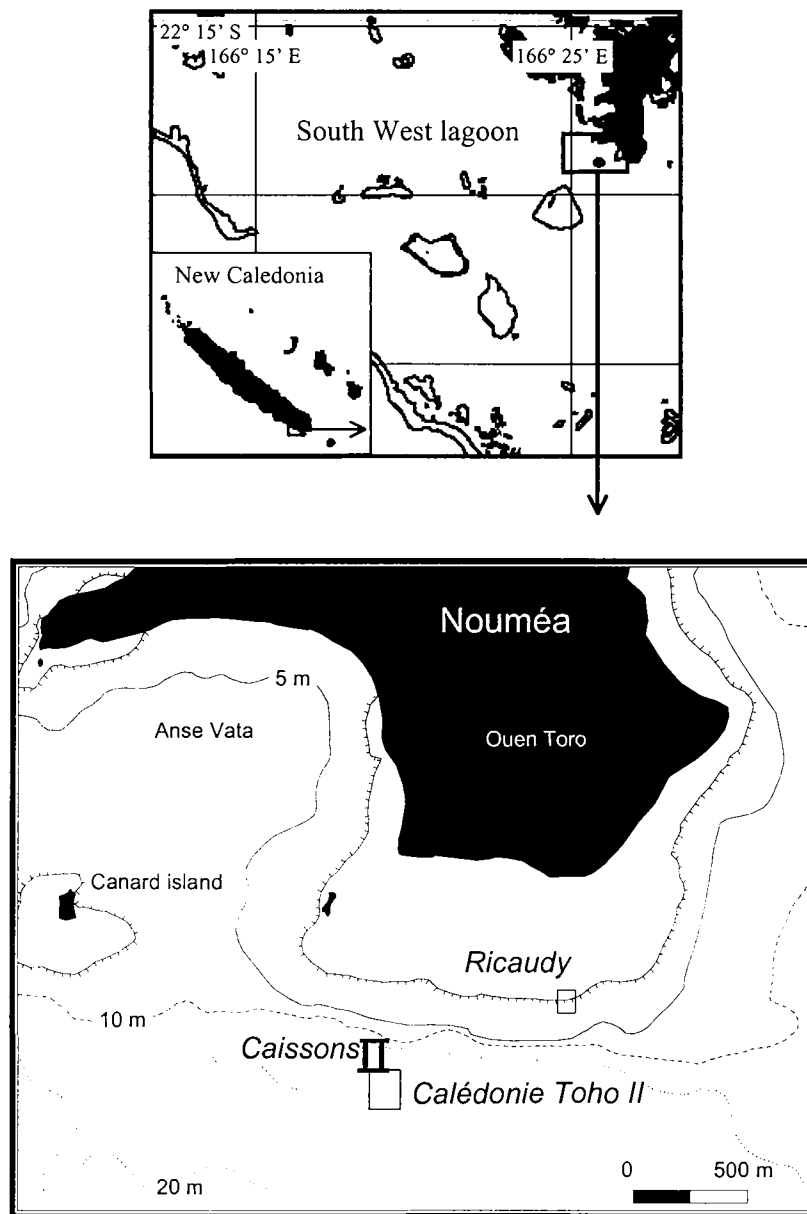


Figure 1. Location of the study area.

COLONIZATION OF THE *F/V CALÉDONIE TOHO 2* WRECK BY A REEF-FISH ASSEMBLAGE NEAR NOUMÉA (NEW CALEDONIA)

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ABSTRACT

The colonization of the *F/V Calédonie Toho 2* was studied for a period of 13 months after the ship was scuttled. A nearby assemblage of US Marine floating bridge boxes (*Caissons*) sunk during WWII and a natural fringing reef (*Ricaudy*) were surveyed at the same time. Species richness on the *Calédonie Toho 2* increased to reach 42 species 398 days after scuttling. Fish density increased for 109 days after scuttling to reach a mean of 8.15 fish/m², with exceptional peaks during recruitment phases. Fish biomass increased in two steps to reach an average of 336 g/m² 193 days after scuttling. The number of common species was higher between the *Calédonie Toho 2* and the *Caissons* (54 species) than *Calédonie Toho 2* and *Ricaudy* (20 species). *Ricaudy* fish assemblages were characterized by species associated with live corals whereas the artificial reefs were characterized by pelagic and opportunist species. Differences occurred between the *Calédonie Toho 2* assemblage, characterized by numerous sciophylous species (Apogonidae), and the *Caissons* assemblage, characterized by large carnivorous species (Serranidae, Lutjanidae). These differences were due to the different size, shape and age of the two artificial reefs. The *Calédonie Toho 2* assemblage evolved from a pioneer to a "secondary" assemblage, with four species assemblages being successively identified. The first step of the colonization was the arrival of large fish from the *Caissons* and the recruitment of *Chromis fumea* (Pomacentridae). The other species assemblages were characterized by seasonal recruitment of juveniles and migration of pelagic and opportunist adult fish species. The "secondary" assemblage was characterized by an increasing migration of adults of specialized benthic species despite the persistence of a pool of pelagic and opportunist species. Consequently, the *Calédonie Toho 2* acted more as an attraction device located on bare sand than a productive structure for the surrounding environment during the first 13 months after the scuttling.

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INTRODUCTION

Artificial reefs have been widely used in the marine environment to enhance fishing yields because of their capacity to attract and aggregate fish. However, this use may accelerate the decline of heavily exploited fish stocks by concentrating fish and fishing efforts into a restricted area, rather than contributing to enhance fish production through growth, reproduction and survival processes. This attraction-production debate has been widely discussed (among others, Bohnsack, 1989; Chou et al., 1992; Bohnsack, 1996; Carr and Hixon, 1997; Grossman et al., 1997; Pickering and Whitmarsh, 1997). Each case is different because numerous factors are involved such as reef design, reef location, fishing effort and management policy (Chou et al., 1992; Brock, 1994; Bohnsack, 1996; Chou, 1997). Currently, man-made reefs are used as a management tool to compensate for overfishing and anthropogenic degradation (Grove, 1982; Chou et al., 1992; Bohnsack et al., 1997; Chou, 1997). They provide new habitats for juveniles and adults, and contribute to protecting resources if fishing is restricted around the artificial reef (Bohnsack, 1989; Chou, 1997; Grossman et al., 1997). If artificial reefs are located in the coastal zone for mitigation purposes, they can induce economic benefits other than fishing when used for ecotourism and scuba diving. This may be the most economically viable use of an artificial reef (Brock, 1994).

In New Caledonia, artificial reefs located in the lagoon have several origins. There are several shipwrecked vessels generally located near natural reefs, remains of US military equipment from World War II (*Caissons*) sunk in the lagoon near Nouméa, and two vessels recently sunk by local authorities for scuba diving purposes. In 1996, the Service de la Mer de la Province Sud had the opportunity to sink a third vessel, *F/V Calédonie Toho 2*. The ship was sunk to create a scuba diving site near Nouméa where tourism activity is concentrated.

After the scuttling of the ship, the Service de la Mer de la Province Sud funded a scientific survey in order to study the colonization of the wreck by a fish assemblage. The different steps of the colonization process and the identification of ecological changes were analyzed. Species similarity on a nearby artificial reef (*Caissons*) and the closest natural reef (*Ricaudy*) was assessed. This study of the colonization by a fish assemblage contributes to the understanding of the attraction-production debate. The proximity of the *Caissons* allowed quantifying the interactions between the new artificial reef and the surrounding communities. The results are of particular interest in the coral reef environment because of a lack of scientific data (Carr and Hixon, 1997). Moreover, most artificial reefs studied are quarry rocks, concrete blocks, old tires and oil production platforms but shipwrecks have seldom been studied.

MATERIAL AND METHODS

The *F/V Calédonie Toho 2* (CT2) was a Japanese long-liner (length 44.7 m, width 7.6 m and height 15 m including upper works) of 121-ton burden (one-ton burden represents a weight of 1,000 kg and a volume of 1 m³). The ship was sunk August 9, 1996 near Nouméa (Fig. 1). It lies on its starboard, at a depth of between 20 and 23 m, on a muddy sand substrate with scarce epibenthic organisms: alcyonarians

(*Spongodes merleti*); holothurians (*Actinopyga echinites*); and sea stars (*Protoreaster nodosus*). A few bioclasts, which are colonized by sponges, hydroids, nudibranchs or feather stars (*Himerometra robustipinna*), are present on the sea floor. This type of biotope was identified as "silted bottoms under terrigenous influence" by Richer de Forges et al. (1987). The visibility varied between 5 and 10 m and the main currents were directed from the hull to the deck. Consequently, currents were weak on the deck side of the boat. By the end of the survey, the CT2 was colonized by 22 benthic taxa (algae, sponges, corals, anthozoa, mollusks, crustaceans, echinoderms and sea squirts).

The *Caissons* are made of an assemblage (19 x 19 m, maximum pile height 6 m) of 30 iron US Marine floating bridge boxes (2 m side) sunk between 1942 and 1945. They are located between 17 and 20 m depth in the same biotope as the CT2 (Fig. 1). The nearest box is located 7 m from the stern of the wreck. The boxes, sunk more than 50 years ago, are heavily corroded and colonized by 29 typical hard-bottom benthic flora and fauna taxa (algae, sponges, corals, alcyonarians, anthozoa, mollusks, crustaceans, echinoderms and sea squirts).

The closest natural reef formation, *Ricaudy* fringing reef (Fig. 1), 280 m away from the CT2 and between 1 and 3 m depth, is characterized by a windward outer slope with live corals, mainly branching *Acropora* spp., *Pocillopora* spp., Poritidae and Favidae. The reef flat is characterized by rubble in the upper parts and algae beds (*Sargassum* sp. and *Turbinaria ornata*) in the deeper parts. This reef was used as a reference station.

Census of Fish

The fish assemblages of the three sites (CT2, *Caissons* and *Ricaudy*) were regularly sampled during the 13 months following the scuttling of the boat (Table 1). Sampling frequency was higher at the beginning of the survey in order to identify initial fish colonization accurately. The stations were sampled once a week during the first two months, once every two weeks during the following two months, and once a month during the last nine months. The frequency was occasionally modified because of bad weather conditions (hurricane, tropical depression), mainly for *Ricaudy* as this station is inaccessible in high wind. Unfortunately, the *Caissons* fish community was not censused before the blast of the CT2 because the survey was funded after the scuttling. However, qualitative and semi-quantitative observations were made by Chauvet (pers. com.) on the effect of the blast on the *Caissons* fish community. These observations were made on the sea surface and the sea floor just after the blast.

The fish assemblages of the CT2 and the *Caissons* were censused by visual counts (time for each census ranged from 45 to 60 minutes). All fish located inside the structures and in a 5 m perimeter around the artificial reefs were identified and counted by two divers, each diver sampling different fish families. The divers estimated the fork length of the fish. Fish weights were calculated from length-weight relationships (Kulbicki et al., 1993; 1994). The surface areas sampled were 1,067 m² for the CT2 and 856 m² for the *Caissons*.

Table 1. Sampling calendar of the *Calédonie Toho 2*, the *Caissons* and *Ricaudy* reef.

Date	N°	Days	Calédonie Toho 2	Caissons	Ricaudy
20 08 1996	1	11	x	x	x
26 08 1996	2	17	x	x	-
02 09 1996	3	24	x	x	x
09 09 1996	4	31	x	x	-
17 09 1996	5	39	x	x	-
01 10 1996	6	53	x	x	x
15 10 1996	7	67	x	x	x
28 10 1996	8	80	x	x	x
26 11 1996	9	109	x	x	x
09 12 1996	10	122	x	x	x
18 02 1997	11	182	x	x	x
18 03 1997	12	210	x	x	-
11 04 1997	13	234	x	x	x
16 05 1997	14	269	x	x	-
09 06 1997	15	293	x	x	x
18 07 1997	16	332	x	x	x
08 08 1997	17	353	x	x	x
11 09 1997	18	387	x	x	x

N° = sample number; Days = number of days after the scuttling of the *Calédonie Toho 2*; x = sampling completed; - = no sampling.

Distance sampling (Burnham et al., 1980; Buckland et al., 1993) was used to sample the *Ricaudy* fish community. A 50-m line transect was laid on the sea floor. All fish along the transect were identified and counted by the same divers who sampled the artificial reefs. The fork lengths and perpendicular distances of the fish to the transect were estimated. Fish which were more than 10 m from the transect were not recorded.

The divers had a good knowledge of the fish fauna and previous training in visual censuses. Previous works show that differences in length, distance and number estimates are likely to be minor (Wantiez et al., 1997; Kulbicki and Sarramégna, 1999).

Data Analysis

Fish densities and biomasses on the CT2 and the *Caissons* were calculated by dividing numbers and weights of fish by surface areas. On *Ricaudy*, densities and biomass were calculated by the average distances method (Kulbicki and Sarramégna, 1999), i.e.:

$$De = (2L)^{-1} \sum_{i=1}^p n_i d_i^{-1} \text{ and } Bi = (2L)^{-1} \sum_{i=1}^p w_i d_i^{-1},$$

where De = density (fish/m²), L = transect length (50 m), n_i = abundance of species i , d_i = average distance for species i to the transect (m), p = number of species,

B_i = biomass (g/m^2), and w_i = weight of species i (g). Average distance for species i to the transect is calculated as follows:

$$d_i = \frac{1}{n_i} \sum_{j=1}^{o_i} n_j d_j,$$

where o_i = number of occurrences of species i , n_j = number of fish of species i observed at occurrence j , and d_j = distance of fishes i to the transect at occurrence j . These estimations are easy to calculate and yielded values very close to the best fits using complicated algorithms (Kulbicki and Sarramégna, 1999).

Correspondence analysis (Legendre and Legendre, 1984) was used to study the fish assemblage structures of the three sites and to analyze fish colonization of the CT2. This analysis was performed on the data matrix of the density of the species. No data transformations were necessary to clarify the projections of the objects (samples) and descriptors (species) or to identify the different structures and their characteristic species assemblages.

RESULTS

Effects of the Blast

The blast of the CT2 induced some fish mortality in a 40 m perimeter around the boat. The soft-bottom fish community was little affected. Less than 50 specimens of *Lethrinus genivittatus* and *Nemipterus peronii* were killed. The *Caissons* fish community was also affected. The highest mortality affected *Priacanthus hamrur* (around 400 kg). Two other species were significantly affected: *Lutjanus argentimaculatus* and *Lutjanus russelli* (less than 25 kg). The rest of the large species were seldom affected. In particular, no dead Carangidae and Serranidae were censused.

Temporal Variations

A total of 183 fish species was recorded during this survey. Seventy eight species (29 families) were censused on the CT2 with Carangidae (9 species), Pomacentridae (9 species), Apogonidae (8 species) and Lutjanidae (8 species) being the most diversified families. Eighty eight species (30 families) were censused on the *Caissons* with Pomacentridae (11 species), Carangidae (10 species) and Serranidae (9 species) being the most diversified families. One hundred species (23 families) were censused on *Ricaudy* with Labridae (20 species), Pomacentridae (19 species) and Chaetodontidae (15 species) being the most diversified families. Species richness on the CT2 increased throughout the survey (Fig. 2) from 5 species, 11 days after scuttling, to a maximum of 42 species, 398 days after scuttling. Species colonization was most significant during the first 20 days, with the first colonization step involving pioneer species. After that, species richness increased regularly to reach a level of 31-35 species after 221 days.

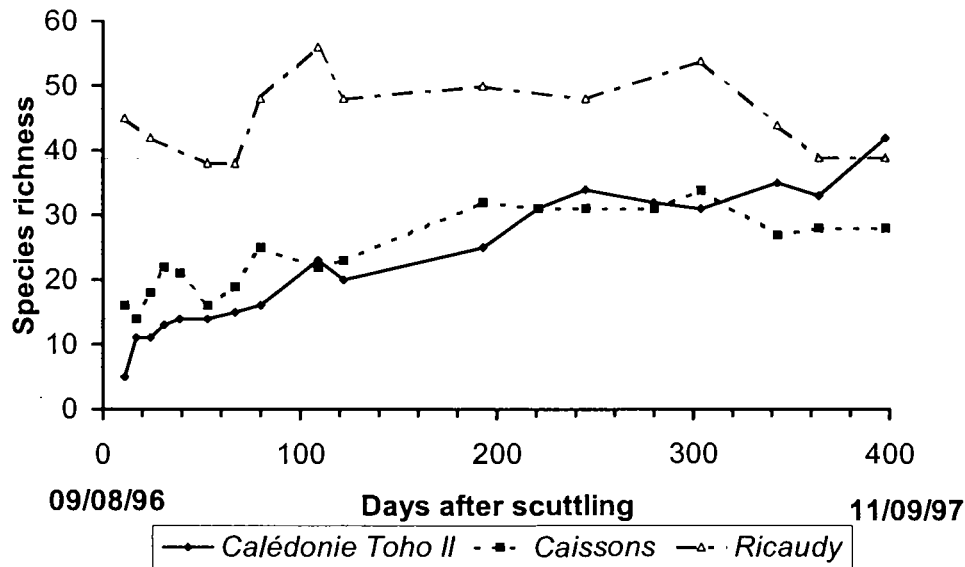


Figure 2. Temporal variations of fish species richness on *Calédonie Toho 2*, *Caissons* and *Ricaudy* reef.

A new increase phase was observed during the final sampling. These species will be referred to as "secondary" species. On the *Caissons*, species richness increased overall during the first 193 days from 16 to 32 species (Fig. 2). After this colonization phase, species richness remained relatively stable at approximately between 28 and 34 species during the rest of the survey. Variations of species richness on the natural reef (*Ricaudy*) were relatively low (Fig. 2). On average, 45 species were recorded during the survey. Species richness was lower in winter (40 species on average), from September to October 1996 (11 to 67 days after scuttling) and from July to mid-September 1997 (343 to 398 days after scuttling). Species richness was higher during the rest of the year (50 species on average). During the survey, species richness was significantly higher on *Ricaudy* than on both artificial reefs (χ^2 proportionality test, $P < 0.05$), with differences between CT2 and *Caissons* not being significant (χ^2 proportionality test, $P > 0.05$).

Fish density increased rapidly during the first 109 days after scuttling (Fig. 3). This increase was mainly due to the settlement of planktivorous schooling species (Clupeidae, Apogonidae and Pomacentridae) and the migration of carnivorous species (Carangidae, Lutjanidae). After this increase, density remained relatively stable (around 8.15 fish/m²) with the exceptional peaks occurring between 304 and 364 days after scuttling. These high values corresponded to the recruitment of Apogonidae, *Rhabdamia* spp. The density of these species decreased dramatically in the last sample because recruitment had ended and because of predation. The schools of Carangidae were feeding on small fish, which ventured out of their shelters (upper works or holds). On the *Caissons*, density increased for 67 days following scuttling (Fig. 3) due to the recruitment of the same small species as on the CT2 and the presence of the same species of Carangidae. The density remained relatively stable between 67 and 193 days, then decreased to an average of 1.32 fish/m². This second level was due to

the end of the recruitment of Clupeidae (*Spratelloides* spp.) while predation by Carangidae persisted. On *Ricaudy*, density remained relatively stable throughout the survey (Fig. 3) with fish population being dominated by parrotfish juveniles (*Scarus* spp.) and adult Pomacentridae (*Abudefduf sexfasciatus*, *Pomacentrus molluccensis* and *Stegastes nigricans*). At the end of the survey, fish density was highest on the CT2 because of the presence of schools of Apogonidae and juveniles, while densities were comparable on *Caissons* and *Ricaudy* (Fig. 3).

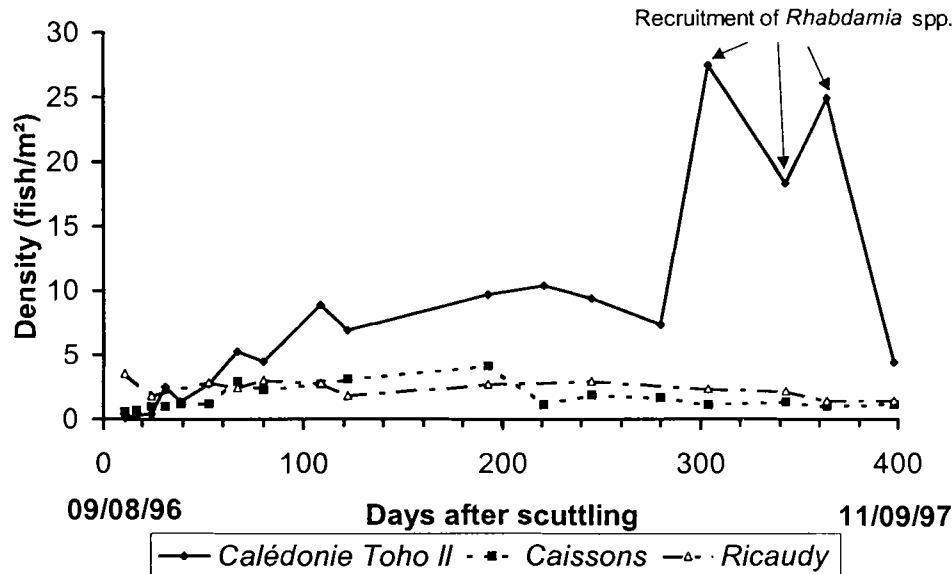


Figure 3. Temporal variations of fish density on *Calédonie Toho 2*, *Caissons* and *Ricaudy* reef.

Fish biomass on the CT2 increased during the 53 days after scuttling (Fig. 4). This increase was mainly due to the migration of *Lutjanus russelli* from the *Caissons*. The biomass stabilized at an average of 153 g/m^2 between 53 and 193 days after scuttling. Important variations were observed after this first colonization phase, due to the occasional presence of Carangidae (unidentified Carangidae and *Carangoides dinema*), large *Lutjanus argentimaculatus* and Sphyraenidae (*Sphyraena flavicauda* and *Sphyraena jello*). At the end of the survey, biomass reached an average of 336 g/m^2 . The largest fish recorded were rays (*Taeniura melanospila*) of more than 200 kg and five groupers (*Epinephelus coioides*) from 0.5 kg to 13 kg, the first specimens being recorded 11 days after scuttling. On the *Caissons*, mean biomass remained relatively stable (174.3 g/m^2) despite important variations (Fig. 4). With two exceptions (24 and 304 days after scuttling), a school of *Lutjanus russelli* constituted more than 45% of the overall biomass. Biomass variations were mainly related to the fluctuation in size of this school. On *Ricaudy*, biomass remained stable (52.2 g/m^2 on average) during the survey (Fig. 4). At the end of the survey, fish biomass was higher on CT2 and lower on *Ricaudy*.

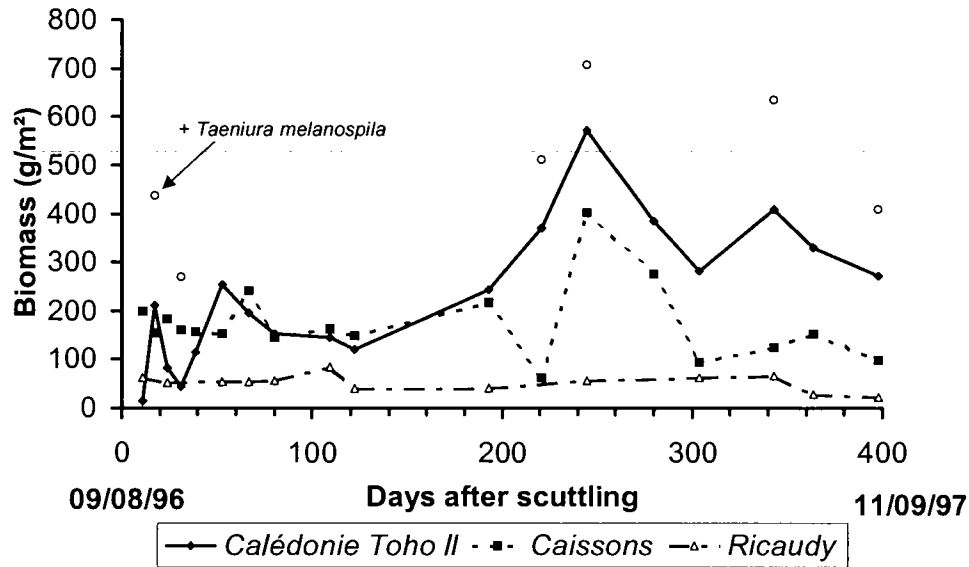


Figure 4. Temporal variations of fish biomass on *Calédonie Toho 2*, *Caissons* and *Ricaudy* reef.

Species Similarity and Fish Assemblages

Fish species were more similar between the CT2 and the *Caissons* than between the two artificial reefs and *Ricaudy* (Fig. 5). Artificial reefs shared 54 species (69.2% of the species recorded on the CT2). On the other hand, only 20 species were censused on both the CT2 and *Ricaudy* (25.6% of the species recorded on the CT2). Only 14 of these species were present on all three sites, mainly planktivores (*Clupeidae*, *Apogonidae* and *Pomacentridae*), macro-carnivorous species (*Plectropomus leopardus*, *Lethrinus lentjan*) and two micro-herbivorous species (*Scarus ghobban* and *Acanthurus blochii*). The number of species in common between the CT2 and the *Caissons* increased during the 245 days after scuttling to reach 22 (Fig. 6). Two groups of species were involved. The first group consisted of species coming from the *Caissons*, which migrated to the wreck. The second group consisted of adult lagoon species, which colonized the two artificial reefs, and juveniles, which simultaneously colonized the two structures. After this phase, the number of species recorded on both artificial reefs remained around 20 with variations linked to the occasional presence of pelagic and opportunist species. The number of species in common between the CT2 and *Ricaudy* increased very slowly (Fig. 6). An average of five species (maximum six species) was seen simultaneously on the two sites.

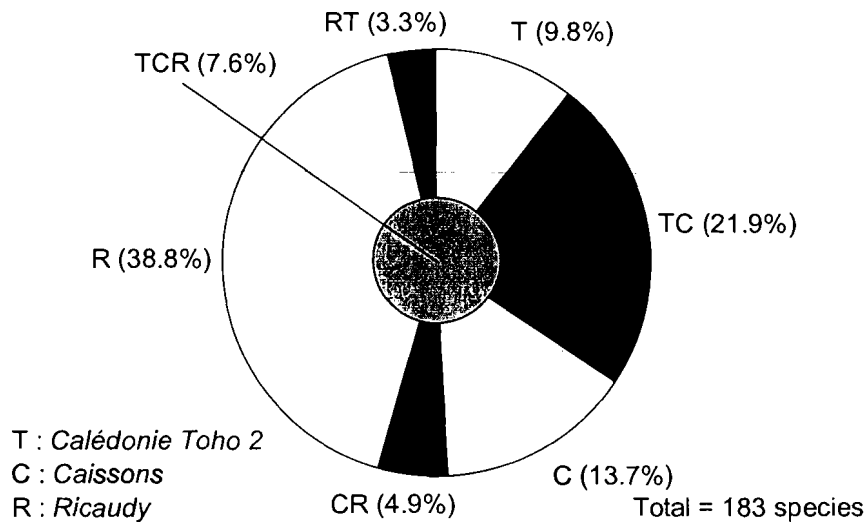


Figure 5. Species similarity among *Calédonie Toho 2*, *Caissons* and *Ricaudy* reef assemblages.

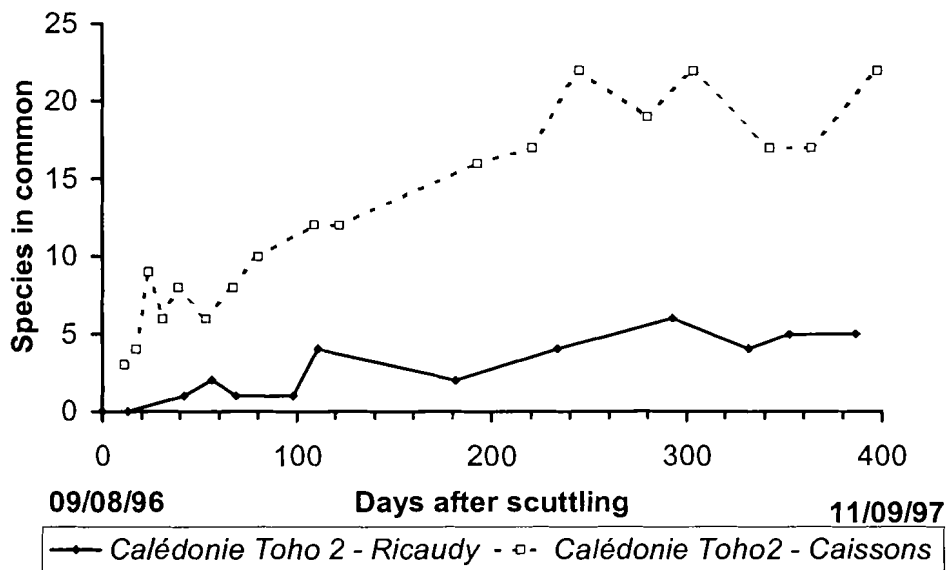


Figure 6. Temporal variations of species similarity between *Calédonie Toho 2*, *Caissons* and *Ricaudy* reef.

Correspondence analysis showed that the fish assemblage structures of the artificial reefs (CT2 and *Caissons*) were different from that of *Ricaudy* reef (Fig. 7). *Ricaudy* fish assemblage was characterized by species with a high coral reef affinity (Table 2): Chaetodontidae (*Chaetodon* spp.), Pomacentridae (*Abudefduf* spp., *Chromis* spp., *Stegastes nigricans*), Labridae (*Halichoeres* spp., *Thalassoma* spp.) and Scaridae (*Scarus* spp.). The artificial reefs were characterized by pelagic species (Clupeidae, Carangidae, Sphyraenidae, *Scomberomorus commerson*), lagoon opportunist species (Lutjanidae, Lethrinidae), large Serranidae, one Caesionidae (*Pterocaesio marri*), one

Priacanthidae (*Priacanthus hamrur*), and recruits of Pomacentridae and Apogonidae (Table 3).

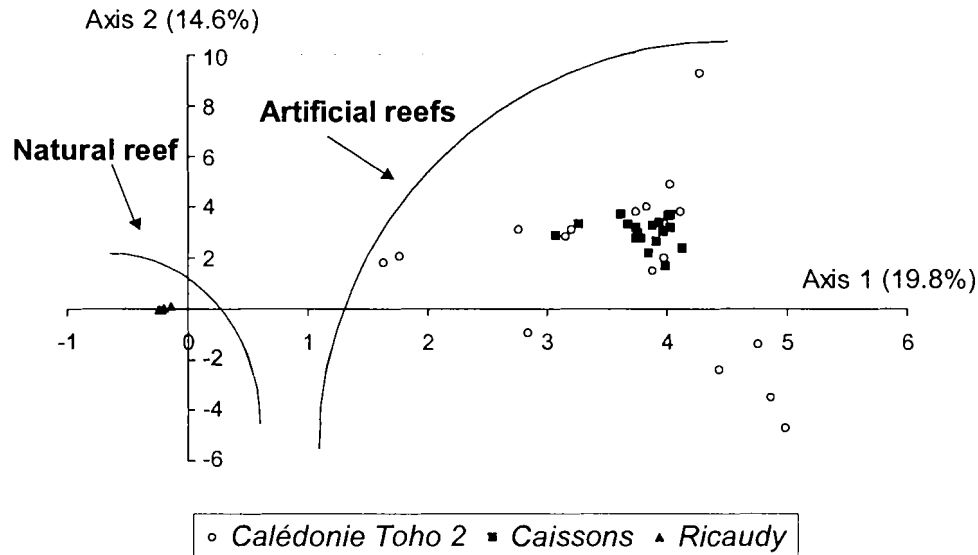


Figure 7. Correspondence analysis of the community structure (projection of the samples) of *Calédonie Toho 2*, *Caissons* and *Ricaudy* fish assemblages. The percentage of the total variance explained by the axes are given.

The fish assemblages of the CT2 and the *Caissons* displayed numerous similarities (Fig. 7). Differences concerned the Apogonidae that recruited on the wreck and the presence of several large Serranidae and Lutjanidae on the *Caissons* (Table 3). Fish community structure of the *Caissons* remained relatively stable during the study, whereas ecological changes affected the CT2 fish community (Fig. 7).

Ecological Changes

Ecological changes were identified by the correspondence analysis performed on the fish assemblages of the CT2 (Fig. 8). A pioneer assemblage was observed during the first 221 days after scuttling (samples 1 to 12; Fig. 8). The recruitment of juveniles and the migration of adults from the *Caissons* or the surrounding lagoon characterized this phase. Three steps were identified during the first 193 days (samples 1 to 11; Fig. 8). During the first 31 days (samples 1 to 4), large adult fish (Serranidae and Carangidae) coming from the *Caissons* and recruits of one species of Pomacentridae (*Chromis fumea*) colonized the wreck (Table 3). The second step took place between 39 and 109 days (samples 5 to 9; Fig. 8). The fish assemblage structure was modified by a massive recruitment of juveniles, mainly Clupeidae, Apogonidae and unidentified Pomacentridae (Table 3). Adults of new pelagic and opportunist species were also censused during this period (Dasyatidae and Carangidae). The third step occurred between 122 and 193 days after scuttling (samples 10 and 11; Fig. 8). During this period, new pelagic species were censused (Carangidae) and one species of Pseudochromidae and one of Scaridae migrated on to wreck (Table 3). In sample n° 12 (221 days after scuttling) the characteristic species of the third step were not censused.

Consequently, this sample displayed similarities with the fish assemblage censused during the second step of this pioneer colonization phase (Fig. 8).

Table 2. Characteristic species of the fish assemblage of *Ricaudy* reef, determined by the correspondence analysis.

<i>Ricaudy</i>		
<i>Tylosurus crocodilus</i>	<i>Chaetodon trifascialis</i>	<i>Halichoeres hortulanus</i>
<i>Sargocentron</i> sp	<i>Chaetodon ulietensis</i>	<i>Halichoeres margaritaceus</i>
<i>Fistularia commerson</i>	<i>Chaetodon unimaculatus</i>	<i>Hemigymnus melapterus</i>
<i>Synanceia verrucosa</i>	<i>Chaetodon vagabundus</i>	<i>Labroides dimidiatus</i>
<i>Epinephelus caeruleopunctatus</i>	<i>Abudefduf septemfasciatus</i>	<i>Stethojulis strigiventer</i>
<i>Epinephelus macrospilos</i>	<i>Abudefduf sexfasciatus</i>	<i>Thalassoma hardwicke</i>
<i>Epinephelus merra</i>	<i>Abudefduf vaigiensis</i>	<i>Thalassoma janseni</i>
<i>Plectropomus leopardus</i>	<i>Abudefduf whitleyi</i>	<i>Thalassoma lunare</i>
<i>Apogon aureus</i>	<i>Amphiprion melanopus</i>	<i>Thalassoma lutescens</i>
<i>Apogon fuscus</i>	<i>Chromis agilis</i>	<i>Thalassoma trilobatum</i>
<i>Cheilodipterus quinquelineatus</i>	<i>Chromis viridis</i>	<i>Chlorurus sordidus</i>
<i>Trachinotus blochii</i>	<i>Chromis chrysur</i>	<i>Scarus</i> sp
<i>Lutjanus fulviflamma</i>	<i>Chromis</i> sp	<i>Scarus altipinnis</i>
<i>Lethrinus harak</i>	<i>Chrysiptera taupou</i>	<i>Scarus rivulatus</i>
<i>Lethrinus lentjan</i>	<i>Neopomacentrus violascens</i>	<i>Scarus ghobban</i>
<i>Lethrinus atkinsoni</i>	<i>Neoglyphidodon melas</i>	<i>Scarus schlegeli</i>
<i>Lethrinus obsoletus</i>	<i>Neoglyphidodon polyacanthus</i>	<i>Blenniidae</i> spp
<i>Scolopsis bilineatus</i>	<i>Plectroglyphidodon leucozonus</i>	<i>Acanthurus blochii</i>
<i>Scolopsis trilineatus</i>	<i>Pomacentrus bankanensis</i>	<i>Acanthurus triostegus</i>
<i>Parupeneus ciliatus</i>	<i>Pomacentrus moluccensis</i>	<i>Ctenochaetus striatus</i>
<i>Parupeneus indicus</i>	<i>Pomacentrus</i> sp	<i>Zebrasoma scopas</i>
<i>Parupeneus multifasciatus</i>	<i>Pomacentrus vaiuli</i>	<i>Zebrasoma veliferum</i>
<i>Chaetodon auriga</i>	<i>Stegastes nigricans</i>	<i>Siganus argenteus</i>
<i>Chaetodon bennetti</i>	<i>Labridae</i> sp2	<i>Siganus corallinus</i>
<i>Chaetodon citrinellus</i>	<i>Labridae</i> sp3	<i>Siganus doliatus</i>
<i>Chaetodon ephippium</i>	<i>Labridae</i> spp	<i>Siganus puellus</i>
<i>Chaetodon flavirostris</i>	<i>Cheilinus chlorourus</i>	<i>Siganus punctatus</i>
<i>Chaetodon lineolatus</i>	<i>Cheilinus trilobatus</i>	<i>Siganus spinus</i>
<i>Chaetodon lunula</i>	<i>Cheilio inermis</i>	<i>Euthynnus affinis</i>
<i>Chaetodon lunulatus</i> ¹	<i>Choerodon fasciatus</i>	<i>Oxymonacanthus longirostris</i>
<i>Chaetodon melannotus</i>	<i>Choerodon graphicus</i>	<i>Arothron hispidus</i>
<i>Chaetodon plebeius</i>	<i>Gomphosus varius</i>	<i>Arothron manillensis</i>
<i>Chaetodon speculum</i>	<i>Halichoeres argus</i>	

¹: sister species of the Indian Ocean species *Chaetodon trifasciatus*

Table 3. Characteristic species of the fish assemblages of the *Calédonie Toho 2* and the *Caissons*.

Characteristic species of the <i>Calédonie Toho 2</i> and the <i>Caissons</i>		
<i>Cephalopholis urodeta</i>	<i>Symphorus nematophorus</i>	<i>Neopomacentrus</i> sp1
<i>Epinephelus cyanopodus</i>	<i>Pterocaesio marri</i>	<i>Pomacentrus imitator</i>
<i>Priacanthus hamrur</i>	<i>Lethrinus</i> sp	<i>Sphyraena jello</i>
<i>Carangoides dinema</i>	<i>Lethrinus nebulosus</i>	<i>Ecsenius midas</i>
<i>Pseudocaranx dentex</i>	<i>Kyphosus vaigensis</i>	<i>Meicanthus atrodorsalis</i>
<i>Lutjanus adetii</i>	<i>Chaetodon kleinii</i>	<i>Gobiidae</i> spp
<i>Lutjanus argentimaculatus</i>	<i>Centropyge bicolor</i>	<i>Lactoria cornuta</i>
<i>Lutjanus fulvus</i>	<i>Pomacanthus sextriatus</i>	<i>Arothron stellatus</i>
<i>Lutjanus vitta</i>		
Characteristic species of the <i>Calédonie Toho 2</i> only		
Pioneer assemblage (N° 1 to 12)		
<i>Pterocaesio marri</i> (2)		<i>Sphyraena jello</i> (2)
N°1 to 4 (◆)	N°5 to 9 and 12 (◇)	N°10 and 11 (▲)
<i>Taeniura melanospila</i> (2)	<i>Dasyatis kuhlii</i> (2)	<i>Caranx papuensis</i> (2)
<i>Epinephelus coioides</i> (2)	<i>Aetobatus narinari</i> (2)	<i>Trachinotus bailloni</i> (2)
<i>Plectropomus leopardus</i> (2)	<i>Spratelloides</i> sp (1)	<i>Pseudochromis paccagnellae</i> (1)
<i>Caranx melampygus</i> (2)	<i>Apogon doederleini</i> (1)	<i>Scarus rivulatus</i> (2)
<i>Gnathanodon speciosus</i> (2)	<i>Apogon fraenatus</i> (1)	
<i>Lutjanus</i> sp (2)	<i>Sillago</i> sp (2)	
<i>Platax orbicularis</i> (2)	<i>Echeneis naucrates</i> (2)	
<i>Chromis fumea</i> (1)	<i>Carangidae</i> spp (2)	
<i>Bodianus perditio</i> (1,2)	<i>Atule mate</i> (2)	
<i>Acanthurus blochii</i> (2)	<i>Caranx lugubris</i> (2)	
	<i>Pomacentrus</i> sp (1)	
	<i>Scomberomorus commerson</i> (2)	
	<i>Arothron nigropunctatus</i> (2)	
	N° 13 (□)	
<i>Apogon</i> sp (1)	<i>Chrysiptera taupou</i> (1)	<i>Sphyraena flavicauda</i> (2)
<i>Plectorhinchus picus</i> (1)		
Secondary assemblage (N° 14 to 18; ●)		
<i>Pterois volitans</i> (2)	<i>Parupeneus heptacanthus</i> (2)	<i>Labridae</i> sp2 (2)
<i>Epinephelus maculatus</i> (2)	<i>Parupeneus multifasciatus</i> (2)	<i>Scarus ghobban</i> (2)
<i>Apogon aureus</i> (1)	<i>Chaetodon lineolatus</i> (2)	<i>Ptereleotris</i> sp (2)
<i>Apogon fuscus</i> (1)	<i>Coradion altivelis</i> (2)	<i>Siganus argenteus</i> (2)
<i>Archamia fucata</i> (1)	<i>Heniochus acuminatus</i> (2)	<i>Ostracion cubicus</i> (2)
<i>Cheilodipterus quinquelineatus</i> (1)	<i>Chrysiptera starcki</i> (1)	<i>Arothron manillensis</i> (2)
<i>Rhabdamia</i> sp (1)	<i>Neopomacentrus azysron</i> (1)	<i>Canthigaster bennetti</i> (1)
<i>Aprion virescens</i> (2)	<i>Pomacentrus coelestis</i> (1)	<i>Canthigaster valentini</i> (1)
<i>Lutjanus kasmira</i> (2)	<i>Sphyraena putnamiae</i> (2)	alevins indéterminés (1)
<i>Lethrinus lentjan</i> (2)		
Characteristic species of the <i>Caissons</i> only		
<i>Gymnothorax javanicus</i>	<i>Cephalopholis sonnerati</i>	<i>Selar crumenophthalmus</i>
<i>Synodus dermatogenis</i>	<i>Cephalopholis</i> sp	<i>Lutjanus fulviflamma</i>
<i>Syngnathidae</i> spp	<i>Epinephelus</i> sp	<i>Lutjanus russelli</i>
<i>Cephalopholis boenack</i>	<i>Caranx sexfasciatus</i>	<i>Diagramma pictum</i>
<i>Cephalopholis miniata</i>		

N° = sample number (Table 1); 1 = juveniles; 2 = adults. Symbols refer to Figure 8.

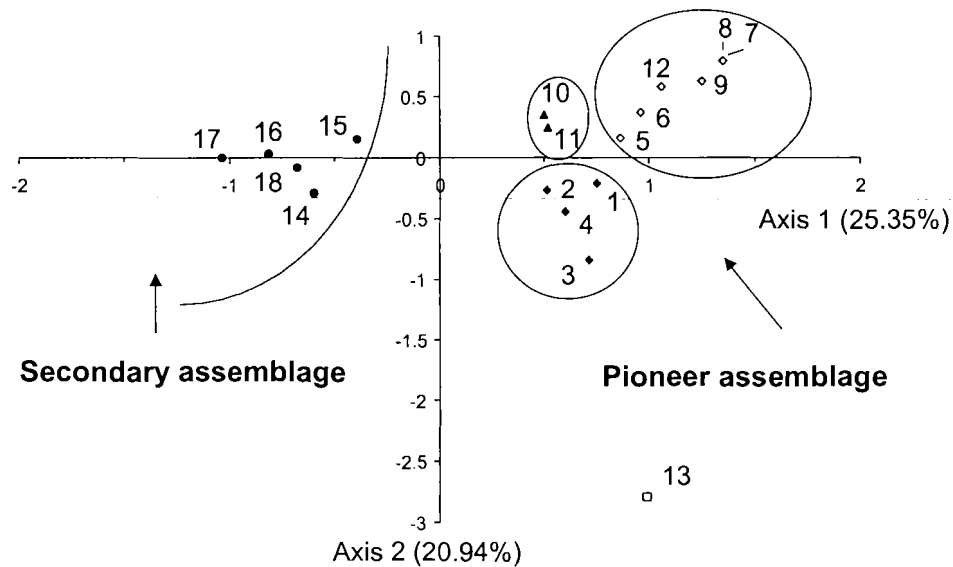


Figure 8. Correspondence analysis of the temporal variations of the community structure (projection of the samples) of *Calédonie Toho 2* fish assemblage. The percentage of the total variance explained by the axes are given. The numbers of the samples are in chronological order (see Table 1).

The fish assemblage structure was different 245 days after scuttling (sample 13; Fig. 8). This sample was characterized by the same species as in the pioneer assemblages and by the recruitment of Apogonidae and the migration of a school of Sphyraenidae from the lagoon (Table 3). This sample can be considered as a transitory assemblage from a pioneer assemblage to a more evolved one.

From 280 days after scuttling to the end of the survey (sample 14 to 18), the fish assemblage on the CT2 evolved to a "secondary" assemblage (Fig. 8). This phase was characterized by the recruitment of five species of Apogonidae and three species of Pomacentridae (Table 3). Adults of Scorpaenidae, Lutjanidae, Chaetodontidae, Scaridae, Siganidae, Ostraciidae and Tetraodontidae characterized this secondary assemblage (Table 3). Some of these secondary species were not censused on the *Caissons* (Scorpaenidae, Lutjanidae, Siganidae, Tetraodontidae).

DISCUSSION

Natural Variations

Temporal variations of species richness, density and biomass on *Ricaudy* reef were typical of fringing reefs in New Caledonia (Kulbicki, 1991), Tahiti (Galzin, 1985) and La Réunion (Letourneur and Chabanet, 1994). These variations are linked to natural processes such as recruitment patterns during summer (Molina, 1982; Galzin, 1985; Letourneur and Chabanet, 1994; Caley, 1995). Consequently, no particular event occurred during this study.

Temporal Variations

The colonization of the CT2 by a fish assemblage was characterized by a rapid increase in species richness, density and biomass because of the proximity of the *Caissons*. Migration of adult fish to the CT2 contributed to the colonization of the ship. Although rapid colonization of artificial reefs by fish has been well documented (Bohnsack et al., 1994; Cummings, 1994), no study on the colonization of a similar artificial reef (type, size, shape and habitat location) was available. Carr and Hixon (1997) studied fish colonization on small structures (4 m²). They reported an increase of species richness during the first 210 days after the start of their survey, as in the present study. However, because of the size of the CT2, it is likely that further colonization of new species will occur with the development of benthic organisms on the wreck.

The rapid increase of the fish density on new artificial reefs is a common characteristic (Pickering and Whitmarsh, 1997). Bohnsack et al. (1994) reported rapid increases of fish density on new artificial reefs with peak levels occurring within two months. This increase phase lasted eight months in the study of Carr and Hixon (1997). During the present study, a leveling off, characterized by higher fluctuations in numbers, appeared within three months. After the first colonization phase, mean densities (eight to nine fish/m²) were similar to those reported by Carr and Hixon (1997). This latter result could suggest that the carrying capacity of the CT2 should be around these values with the exception of occasional peaks related to recruitment phases or the sporadic presence of pelagic schools. Bohnsack et al. (1994) also reported rapid increase in biomass. A similar pattern was observed on the CT2. If the mean density of fish on the CT2 remains approximately eight to nine fish/m², biomass should increase to more than 300 to 350 g/m² with the growth of the surviving recruits and adults.

The initial increase of species richness and density observed on the *Caissons* was probably linked to the effects of the blast of the CT2 on the fish assemblage (migration) and recruitment. However, the observations gathered after the blast showed that it affected a significant number of fish from a limited number of species. These observations were confirmed by the fact that the fish community structure of the *Caissons* was not significantly modified during the survey. After this colonization phase, variations were due to natural processes (recruitment, predation, mortality) and migration of adults to the CT2.

This study showed that species richness is higher on natural reefs than on nearby artificial reefs because of a higher habitat complexity (among others, Chou et al., 1992; Bohnsack et al., 1994; Carr and Hixon, 1997; Chou, 1997; Pickering and Whitmarsh, 1997; Rooker et al., 1997). At the end of the survey, species richness was higher on the CT2, sunk 13 months before, than on the *Caissons*, sunk more than 50 years ago. This result confirms that species diversity is linked to the size and the structural complexity of the artificial reef (Pickering and Whitmarsh, 1997), which are more significant on the CT2. The height of the structure acts as a visual or audio stimulant or spatial reference to attract transient species (Pickering and Whitmarsh, 1997). The structural complexity also influences community diversity by providing numerous shelters with different habitat characteristics (light, crevice, current, etc.).

Densities are higher on artificial reefs than on natural reefs (Chou et al., 1992; Bohnsack et al., 1994; Pickering and Whitmarsh, 1997). However, Carr and Hixon (1997) found contrasting results because they studied small artificial structures (4 m²) with limited habitat complexity. Bohnsack et al. (1994) compared similar artificial reefs of different sizes. They found higher density on the smallest structures. In the present study, the density was higher on the CT2 (largest structure) than on the *Caissons* (smallest structure) because the two structures were not of the same type.

Biomass is higher on artificial reefs than on natural reefs, reflecting the attraction of benthic and pelagic predators (Chou et al., 1992; Pickering and Whitmarsh, 1997; Rooker et al., 1997). The highest biomass on the largest structure was also reported by Bohnsack et al. (1994).

Species Similarity and Fish Assemblages

The fish community of the natural reef (*Ricaudy*) had few species in common with the two artificial reefs studied (CT2 and *Caissons*). The species assemblage structures were also different. The species characterizing the *Ricaudy* fish community are usually found on flourishing shallow fringing reefs (Randall et al., 1990; Thollot et al., 1990; Lieske and Myers, 1995; FishBase, 1997). This confirms the observation that the greater the difference in geomorphologic characteristics of habitats, the greater the difference between natural and artificial reef fish assemblages (Chou et al., 1992). In the present study, the artificial reefs are deeper than *Ricaudy*, which has an influence on the resident species that colonize on the artificial reefs (Rooker et al., 1997).

Organic matter and phytoplankton productivity are linked to artificial reef productivity (Bombace et al., 1994). The site where the CT2 was sunk is a productive environment under terrigenous influence. This productivity explains the presence of numerous planktivores (Clupeidae, Caesionidae, Pomacentridae) and their predators (Carangidae) on the wreck and on the nearby *Caissons*. Current patterns also play an important role in the attraction of fish species. Small pelagic species are attracted by current variations and vortex around artificial reefs (Vik, 1982; Bleckman, 1986). The CT2 lies perpendicular to the main currents, which are directed from the hull to the deck. This optimizes the attraction effects of the currents. Juvenile and small fish colonize the deck and the upperworks where the current is weaker.

Fish assemblage on artificial reefs is related to the habitat where they are located (Chou et al., 1992; Pickering and Whitmarsh, 1997). Because the CT2 and the *Caissons* are located in the same habitat and in close proximity, they have similar species assemblages. As the assemblages are also linked to the artificial reef type (Chou et al., 1992; Pickering and Whitmarsh, 1997) and its age, differences were observed between CT2 and *Caissons* assemblages. The fish assemblage of the *Caissons* is the result of 50 years of colonization despite the effects of the blast of the CT2. More sciophilous species (Apogonidae) were seen on the wreck where there are numerous dark shelter areas. More "secondary" species (*Cephalopholis* spp) were observed on the *Caissons* from the beginning of the survey where a diversified benthic flora and fauna have colonized the hard substrate over 50 years.

Ecological Changes

Three categories of species colonized the CT2. The first category regroups pelagic (Carangidae, Scombridae) and opportunist (Lutjanidae, Lethrinidae) species. The former finds food on the wreck and the latter, shelter. The second category concerns small resident reef species (Apogonidae, Chaetodontidae, Pomacentridae, Labridae, Scaridae, among others). The third category consists of large reef species (Serranidae, Acanthuridae and Siganidae) which can venture away from the reef. The relative importance of these species in the assemblages varied over time.

The pioneer assemblage was characterized by the recruitment of juveniles (Clupeidae, Apogonidae, Pomacentridae) on a vacant biotope and the attraction of large adult fish (Carangidae, Lutjanidae, Lethrinidae) from the *Caissons* and the surrounding lagoon. This pioneer assemblage underwent some modifications with the attraction of other pelagic and opportunist species (Carangidae, Sphyraenidae, Scombridae) and the arrival of new recruits (Apogonidae, Pomacentridae). This colonization phase was characterized by variations in the relative abundance of these species related to recruitment and predation intensity. Apogonidae, for example, were always abundant but changes in dominant species occurred.

The secondary assemblages corresponded in diversification with the colonization of secondary and late species (Chaetodontidae, Pomacentridae, Scaridae, Siganidae, Ostraciidae, Tetraodontidae). The development of benthic flora and fauna modified the habitat characteristics, contributing to an increase in complexity of the ecosystem. This probably created new ecological niches suitable for these fish species. Since then fish assemblage has been the result of several processes. There was an interspecific competition to inhabit different parts of the wreck: Apogonidae invaded the dark parts; *Neopomacentrus* spp and *Chromis fumea* constituted small monospecific schools on the deck and around the upperworks where the current is weaker; and Clupeidae and Caesionidae formed large schools above the wreck. The relative importance of the recruiting species and their predators fluctuated as a result of recruitment inputs and predation processes that were observed during the sampling. In the last sample, a recruitment of *Chromis fumea* occurred, which was similar to the one observed during the first sample. These processes will probably continue each year with their importance depending on the interannual recruitment variations.

The ecological changes should not lead to the disappearance of pioneer species in the case of the CT2. These species are still present on the *Caissons* sunk more than 50 years ago. This ecosystem evolved with the colonization of secondary and late species not present on the CT2 (Serranidae), which are more specialized and require more precise habitat characteristics. However, pioneer species remained because of the seasonal recruitment processes and the attraction of their predators. The benthic flora and fauna communities of the CT2 should evolve and become similar to those of the *Caissons*. This trend should lead to the colonization of late fish species, such as those present on the *Caissons*. This is the evolving part of the ecosystem which characterizes the secondary assemblages. Only a few studies examined ecological changes during the colonization of an artificial reef by a fish assemblage. Cumming (1994) reported that succession, as described by Odum (1969), did not proceed beyond the earliest stages on an artificial reef in an environment with frequent physical disturbance. The ecosystem described by Cumming (1994) remained at a secondary stage and late

assemblages did not replace secondary ones, which is quite similar to what was observed during the present study.

Management Implications

This survey brings new data on the attraction-production debate. Attraction of large adult fish from surrounding habitats is confirmed. The CT2 was sunk on bare sand with a nearby oasis (*Caissons*) acting as an aggregating device for recruits of adult fish. However, the productivity of the artificial reefs is still questionable. The artificial reef should be productive if habitat is a limiting factor in the surrounding environment. In this case, the artificial reef will provide space for recruits that would not have otherwise recruited. The species concerned are mostly demersal, territorial reef species. In the present study, CT2 and *Caissons* artificial reefs are located in a productive coastal zone and acted as a recruitment area for small pelagic and demersal reef species. For the former (Clupeidae, Sphyraenidae), the presence of the artificial reefs did not increase productivity of the surrounding lagoon. These juveniles probably would have recruited in the coastal zone even if the artificial reefs were not present. For the demersal reef species (Apogonidae, Pomacentridae), the artificial reefs were more likely to increase production because the pool of recruits appeared to be much more important than the available space for settlement in the area. The recruitment of these juveniles increased the productivity of the environment by high predation on the recruits and the surviving adults. In the present study, these demersal species were not abundant so the productivity increase induced by the wreck should mainly be a result of predation processes.

Local authorities now consider the scuttling of the CT2 to be a success. The fish assemblage has increased rapidly and daily dives are organized by dive centers on the CT2 - *Caissons* assemblages inducing economical benefits. However, we recommend planning a baseline survey in the future, before artificial reefs are sunk, to choose the best suitable site. We also recommend avoiding the use of explosives that may cause substantial mortality if a diversified fish community is present in the area.

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