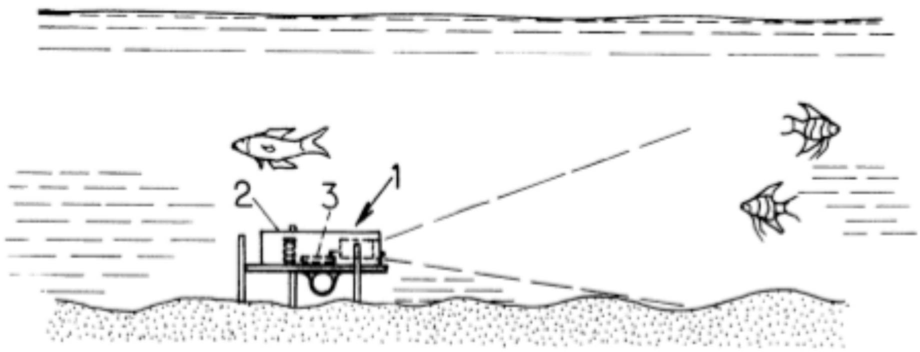
University of Montpellier II University of Aegean

THESIS OF MASTER BIODIV

Marine Biology

Using a moored underwater video system to study the influence of environmental factors on coral reefs fish behaviour



LOISEAU Nicolas
nicolas_loiseau@hotmail.fr
(P.CHABANET & D.PONTON)

Using a moored underwater video system to study the influence of environmental factors on coral reefs fish behaviour

Abstract The present study examined how environmental variables (sea surface temperature (SST), tide, wind velocity and direction, light intensity, and rainfall) influence the structure of coral fishes community around a small coral colony. An autonomous underwater video system fixed on the substrata was used to census fish around a coral colony. The diversity and abundance of fishes were recorded over four consecutive months, seven times per day from sunrise to sunset. A total of 73,880 fishes belonging to 92 species and 23 families were observed. The total number of species (S) and families observed per day, and per sequence, were not influenced by the environmental factors. Environmental variables had significant but weak effect on Serranidae, Haemulidae, Chaetodontidae, Labridae, Scaridae, Siganidae and Acanthuridae and have more important effect on 4 families (Lethrinidae, Lujtanidae, Pomacentridae and juvenile labridae). Up to 50% of the variability in the abundance of Lethrinidae was explained by 4 environmental factors: tide, wind direction, light intensity and sea temperature. Lutjanidae and Lethrinidae presented opposite patterns related to with wind direction and tide. At the species level, *Chromis viridis* (Pomacentridae) were significatively influenced by the light intensity. Our results reveal that tide and light intensity are key factors influencing the patterns of studies families.

Keywords: Video census · Diversity · Coral reef · New Caledonia · *Chromis viridis* · Lethrinidae

Introduction

Coral reefs are not only major storehouses of incredible biodiversity (32 of the 34 recognized animal Phyla are found in coral reef), but they also contribute greatly to socio-economies to coastal population (Wilkinson, 2002). Furthermore, coral reefs are considered as one of the most productive ecosystems in the world (Pillay et al., 2002).

Fishes are an important component of the coral reefs, fulfilling many critical ecological roles (Wilson et al., 2009), and being the major source of food and livelihood for people in tropical coastal areas (Pauly et al., 2002). Coral reef fishes are extremely diverse in terms of families and species when compared to other vertebrate taxa (Claisse et al., 2009), and most the environmental factors that influence their spatial and temporal distributions remain poorly understood. Distribution of reef fishes is determined by a complex series of responses to physical and biological characteristics of their environment including intra and interspecific interaction among species. The responses allow them to select the habitats that offer the best combination for a high potential of growth and reproductive output and the lowest risk of mortality (Gibson et al., 1996).

In order to better understand the factors that influence the distribution of fishes, and more particularly the number of species and individuals that can be observed at a given place, different techniques have been developed. Non-destructive sampling methods, underwater visual censuses (UVC) are the most common techniques used to characterize fish abundance and diversity. (Harmelin-Vivien et al., 1985; Tresher & Gunn, 1986; Samoilys, 1997; Bortone et al., 2000;). However, UVC have bias due to their dependence to environmental conditions and observations may vary with nycthemeral cycle. Human presence underwater is also origin of several biases, changing behaviour of coral fishes. With the advent of digital technologies, video recording has become an appropriate tool for fish surveys (Tessier et al., 2005, Stobart et al., 2007). Compared to UVC, video recordings allow collecting more data in space and/or time, and without an underwater intervention of fish expert, records being performed later in the lab.

Most of the studies using video systems, baited or not, have focused on comparing fish abundance and diversity between several locations, interaction with habitat and evaluation of size and density of fishes or compare the ability of different video monitoring techniques (Watson et al., 2005; Harvey et al., 2002; Langlois et al., 2006; Langlois et al., 2010; Watson et al., 2010). However, fish behaviour has been rarely addressed and remains poorly understood in particular in relation to the effects of environmental factors (Lara & Gonzalez, 2005; Watson et al., 2005). Furthermore, measures at high temporal frequency during high sampling effort have never effected.

In this context, the aim of the present study was to analyse the temporal abundance and diversity patterns of coral fishes in relation to environmental factors (sea surface temperature (SST), light intensity, tide and wind) at high temporal frequency and identifying the environmental attributes that influence the temporal patterns of fish abundance.

Materials and methods

Study area

New Caledonia is located in the southwest Pacific, approximately 1,500 km east of Australia (Figure 1). Due to its latitude, New Caledonia is subject to tropical - subtropical environmental conditions with two distinct seasons: a dry and cold season from June to November and a wetter and hotter season from December to April (Quinn et al., 1998). The island is surrounded by the second largest barrier reef system in the world, which encloses a 23,400 km² lagoon. This study was conducted in the 1.88 km² marine protected area (MPA) of “Ile aux Canards” in the southwest lagoon. This part of the lagoon is characterized by SST ranging from 21°C in the cold season to 26°C in the warm season, with an average value of nearly 24° (Debenay, 1988). Winds come from two main directions: the trades winds, which represent 69% of yearly wind occurrence, blow from 60° to 160° (i.e. offshore) with speeds >4m.s^{-1}; westerly winds blow from 220° to 300° (i.e. along shore) with speeds >2m.s^{-1} and represent <12% of yearly wind occurrence (Blaize & Lacoste, 1995). An important coral cover and habitat complexity characterizes the sampling area in particular branching and tabular live (*Acropora* spp).

Sampling protocol

The moored video system consisted in a camera connected to a timer and a hard disk enclosed in a waterproof housing. This housing was connected to an external 12V lead battery which provided >2 months of energy (Fig 2). The lens of the video housing was cleaned every week by hand to avoid natural fouling. The video system recorded 2 minutes sequences at 6 (sunrise), 8, 10, 12am, 14, 16 and 17pm (sunset). The whole system was firmly fixed to the substrate in front of an approx 3m² coral aggregation at 6 meters depth. The system ran continuously from 12 June to 15 July 2009, and from 6 August to 7 October 2009, data being retrieved regularly.

Environmental data collection

Light intensity ($J.cm^{-2}.d^{-1}$), rainfall ($mm.h^{-1}$), wind speed ($m.s^{-1}$) and direction (degree) were recorded every hour by the Météo France environmental station located 4.5 km from the study site (http://france.meteofrance.com/). SST (°C) was recorded every hour at l'Anse Vata at 1.5 km from the sampling station. For the factor tide, hourly water levels obtained from SHOM (www.shom.fr) were converted in daily average water height (Hwater) and daily amplitude (Lambda = difference between maximal and minimal daily value). Hourly values of wind directions were transformed in daily occurrence of "along shore" (60 to 160°), "offshore" (220 to 300°), and "other winds". For all other variables daily averages were calculated.

Data analysis

A total of 731 video sequences obtained over a total of 97 days were obtained. For each video sequence, the number of individuals per species was recorded manually by the same observer (NL). From these records, the numbers of species (S) and of fish families observed per sequence, as well as their percentage of occurrence per day, were calculated. As some species were present on all the sequences, only the maximal values of S and of abundance per day were retained. GLM (generalized linear models) was used to analyze the influence of environmental variables on the diversity (S) and on the abundance for families with a daily occurrence greater than 50%. Assumptions of normality and homogeneity of variance were examined through residual analysis (Lee & Nelder 1996).

Finally a focus on *Chromis viridis* (Pomacentridae) was conducted to examine the impact of environmental factors on this species at each recorded using GLM analysis.

Results

Environmental data

During the sampling periods, SST ranged from 20.3 to 24.7°C (mean = 22.3°C) and light intensity varied from 0 to 364 $J.cm^{-2}.d^{-1}$ (mean=129 $J.cm^{-2}.d^{-1)}$. Differences in light intensity and SST between days were not important but increased along the sampling period. Wind speed ranged from 0 to 15 $m.s^{-1}$ (mean = 4.5 $m.s^{-1}$). Trade winds were dominant, followed by those from the other category and westerly winds with 69, 18, and 13% of occurrence respectively. The daily amplitude of water levels ranged from 48 to 119 cm. As sampling took place during the dry season, the rainfall values were extremely low, and comprised only very few rainy events that were not retained in subsequent data analyses.

Fish diversity

A total of 73,880 fishes belonging to 93 teleost species and 23 families were recorded (Table 1). The most abundant fish observed were Pomacentridae (damselfishes, 79 individuals observed par day in average), followed by Siganidae (rabbitfishes), Labridae and

Lethrinidae (emperors, 27, 8 and 5 ind/day respectively). The most diverse family was Chaetodontidae (butterflyfishes) with 11 species recorded during the sampling, followed by Acanthuridae (surgeonfishes) and Scaridae (parrotfishes, 10 and 9 species respectively). Pomacentridae were the most often observed with an occurrence per day >99%, followed by Lethrinidae, Labridae and Lethrinidae with occurrence >80%. Among the 23 families recorded, 11 had an occurrence >50%. *C. viridis* is the most abundant and permanent species (occurrence >75%), presented in more of 98% records.

Successive hierarchical generalized linear models (GLM)

Juvenile of Labridae were considered separately from the adults in the analyses, as they were more present in the records. The total number of species (S) and families observed per day, and per sequence, were not influenced by the environmental factors (GLM, P>0.05 for all factor). Environmental variables had significant but weak effect on seven studied families, Serranidae, Haemulidae (grunts), Chaetodontidae, Labridae, Scaridae, Siganidae and Acanthuridae (Table 2). As environmental variables explained less 15% of the abundance of these families, tide and light intensity were the most important factors to explain the variation in abundance of these families.

However, environmental factors had strongly effect on the three remaining families (Lutjanidae, Pomacentridae and Lethrinidae) and juvenile labrids. As they explained 28.7, 28.9, 31.2 and 49.8% of the abundances of juvenile Labridae and Lethrinidae, respectively. Once again tide was the most explicative factor of abundance of these families. When daily variations of height of water (Lambda) were important, the abundances of lutjanids and labrids were higher and those of juvenile labrids lower. More lethrinids, and less lutjanids were observed when winds were blowing along shore, the latter being more abundant when winds were coming from the west. Wind velocity, SST and light intensity had a strong negative influence on the abundance of Pomacentrids and juvenile labrids but the last two variables influenced positively the abundance of lethrinids.

Concerning *C. viridis* abundance were decreasing with the rise of light intensity and significatively explained by light intensity (p-value < 0.001).

Discussion

Underwater observations

Ichtyofauna is particularly rich in New Caledonia coral reefs fishes with 1656 species recorded (Grimaud & Kulbicki, 1998). In order to better understand factors, which influence this diverse fish community, underwater observations were required. The video system developed here allowed observing fish population at high frequency (7 times per day) during four month with only one take-out of the camera in the middle of the sampling program for battery maintenance (complete autonomy of 2 months). The sampling method was also efficient as up to 70,000 fishes were recorded and only one species was undetermined on the 92-recorded species during our sampling period. Furthermore, 52.3% of the species were recorded on the basis on our sampling area compared to the overall MPA surface (unpublished data). Absence of scuba-diver disturbances and short temporal scale also allowed observing unusual fish behavior (swimming association between lujtanids and jacks, movement of moray eels inducing strong fish activity in particular lutjanids and lethrinids). The high level in diversity and abundance recorded in an area of 3 m^2 could be explained by the high complexity of the substrate and high live coral cover inside MPA of Ile aux Canards. The tabular *Acropora* spp characterizing the sampling area is the favourite biotope of *C. viridis* and *Pomacentrus mollucensis* (Pomacentridae), species that were seen permanently on the images recorded. Parrotfishes (Scaridae), butterflyfishes (Chaetodontidae) and snappers (Lutjanidae) have also significantly higher abundance in important coral cover area (Lirman, 1999; McClanahan & Arthur, 2001) as recorded in our study. Finally, with the advent of digital technologies, video recording has become an appropriate tool for fish surveys (Tessier et al., 2005). The technology developed here is characterized by a low cost, and requires fewer times compared to scuba diving campaign (Table 3).

Influence of environmental factors

Diversity of the sampling area was not influenced by environmental factors. Relationship between fish diversity and environmental have been rarely documented. Unsworth & al. (2007) have observed that species richness of coral fishes of Indonesia significantly decreased during tidal reduction. The number of observed species defines diversity, however species richness is a simplistic measure of natural communities (Wilson et al., 2009) resulting from complex processes such as competition, predation, recruitment, disturbances and immigration. (Mora et al., 2003). Shift in species composition is hardly detectable. Departure of one species of the sampling area could induce rapidly arrival of a new species.

Relationship between temporal variations in the fish abundance and environmental variables was rather weak. However some trends were observed, except for Scaridae (parrotfishes) and Serranidae (groupers). This result could be explained by the fact that groupers are nocturnal species spending most of their time under rock and coral during the day (Springer & Erlean, 1962) away from the influence of environmental factors. Majority of groupers recorded was sleeping in a shelter visible on video sequences.

Tide was the most important factor that explained fish abundance, in particular Lambda, which is linked to tidal range. It was noted that, reduction of tides amplitude, from 2.0 m to 0.8 m corresponded to a 30% reduction in fish abundance (Unsworth et al, 2007) and corresponded in our sampling area to the decrease of the number of individuals of five families (juvenile Labridae, Lutjanidae, Acanthuridae, Chaetodontidae and Haemulidae). Tide could create currents followed by mobile fishes like lethrinids and lutjanids. Lutjanids have been shown to undertake daily feeding migrations and move 1000 m or more per tidal cycle between the deep, low tide channels and the shoreward margin of the tidal flat (Nagelkerken et al., 2000, Morrison et al., 2002). These migrations are caused by variation in availability and abundance of suitable food resources, generated by current created by tide (Gibson et al., 1996; Unsworth et al., 2007).

Wind speed is one of the most important environmental factors affecting marine organisms, size and distribution (local and geographical) of population (Moore, 1975; Grove, 1985; Arntz & Fahrbach, 1996; Glynn, 1988). Like tide, winds create currents, influencing dispersion and survival of plankton population (MacKenzie & Leggett 1991) that could make more difficult feeding for plankton-feeders. This phenomenon could explain the lowest abundance of pomacentrids and juvenile labrids during periods characterized by high wind speed. Turbidity created by high wind could also be at the origin of the diminution of pomacentrids and juvenile labrids. In fact turbidity ameliorates predator consumption of prey, reducing the survival of prey (Abrahams & Kattenfeld, 1997). Pomacentrids and juvenile labrids are typically target of fish predator; augmentation of the feeding predator could force individuals of these families to retreat in their shelter. Direction is as important as velocity affecting fish. This study has demonstrated that assemblages of lutjanids, lethrinids display distinctive patterns of abundance with wind direction: more lutjanids were recorded when winds were blowing offshore (Fig 2, a) and more lethrinids when blowing along shore (Fig 2, b). Study on the Great Barrier Reef in Australia has demonstrated similar influences of wind direction on presettlement of lethrinids and lutjanids. Abundances of juvenile lethrinids were generally low during periods of low strength offshore winds and a peak abundance of the lutjanids occurred after periods of offshore winds (Kingsforad & Finn 1997). Wind direction appears as key factor in ecology of lutjanids and lethrinids, influencing two stages of their life history. External forces, such as wind, influence the surface layer conditions of the ocean, especially high wind. There are few observations on the potential interactions of this environmental factor with fish. However, Gibson et al. (1996) found no relationship between fish abundance and wind strength and direction on a Scottish sandy beach. Lasiak (1984), found that the wind speed averaged over the preceding 12 to 48 h had a greater influence on fish abundance than that recorded at the time of sampling.

With augmentation of the SST, abundance of lethrinids and juvenile labrids changed. Abundance of lethrinids increased while juvenile labrids decreased. Temperature influences physiological variables in fishes including food consumption, growth and metabolic rates (Myrick & Cech 2000). It can affect mortality, growth and reproductive rates of individuals, size and distribution of populations and structure of communities and ecosystems (Mora & Ospõana, 2001).

As SST, light intensity increased along the sampling. Lethrinids were significantly more abundant during high light intensity, whereas less pomacentrids and juvenile labrids were observed. Photoperiod is perceived by pineal photoreceptors and transduced into rhythmic melatonin signals. These rhythms and fish predation can be influenced by light intensity (Vera et al., 2009, Leech et al., 2009).

Augmentation of light intensity and SST are linked to seasonality of these parameters. The rise of these factors created changing in abundance patterns of lethrinids, pomacentrids and juvenile of labrids. Influence of season on fish abundance has been demonstrated several times (Allen, 1982; Santos & Nash, 1995; Lincoln-Smith et al, 1994; Burt et al, 2009). Seasonal variations of SST and light intensity in the Caledonian lagoon are small in comparison to experiences realized in temperate ecosystems. Typically, it appears that in areas where the seasonal variation in SST is considerable (>20°C) such as beaches in the Gulf of Mexico, on the Atlantic coast of the United States and in the Persian Gulf seasonal, fluctuations in fish abundance are very pronounced (Clark & al 1996). However, seasonal fluctuations induce changing in fish abundance of the sampling area in MPA of Ile aux Canards.

Chromis viridis

C. viridis is plankton feeder, which live in aggregations above branching *Acropora* corals in sheltered areas such as subtidal reef flats and lagoons. Behaviour of *C. viridis* is influenced by light intensity. This effect was already known as the species has a diurnal feeding activity but this behaviour is also strongly influenced during the day by any solar radiation decrease. Its presence in the water column corresponds of the feeding stage; *C. viridis* go out from their natural shelter to catch zooplankton. When light intensity is reduced by environmental event, its diurnal activity is transformed in the nocturnal behavior during the middle of the day. Foraging activity could be linked to vision as *C. viridis.* Foraging success is being strongly dependent on its ability to recognize its preys. It has already been suggested that special visual adaptations of *C. viridis* such as ultraviolet vision and polarization sensitivity have evolved to increase visibility of transparent plankton during high solar radiation (Hawryshyn & al 2003).

Conclusion

The present study provides a snapshot of temporal abundance and distribution patterns of fishes in the MPA Ile aux canard. It is a first step towards understanding spatio-temporal dynamics of fishes influenced by environmental factors. The result stresses the complex relationship between environmental factors. Although the environmental variables explained a maximum of 49.8% of the variation in fish abundance, these results still contribute to a better understanding the importance if environmental parameter on fish behaviour. Furthermore they reinforce the importance of tide and light intensity as key environmental agents influencing fish dynamics at this location. Finding underlines the specific response of species, which could vary considerably among families (illustrate by *C. viridis*).

Finally, a best knowledge of behavior of fishes in relation to environmental factors could be help to improve the monitoring of coral reef fishes. Additionally, such as UVC, video systems assembled in network should have important application for management and survey in MPA and in distant area.

Acknowledgements: We thank volunteers of the MPA of the Ile aux Canards for their maintenance of the video system. Christophe Cadet & Gerard Mou-Tham for their ability to identify fish.

References

Abrahams M.V & Kattenfeld M.G (1997) The role of turbidity as a constraint on predator-prey interactions in aquatic environments. Behavioral Ecology and Sociobiology 40, 169-174.

Allen L.G (1982) Seasonal abundance, composition, and productivity of the littoral fish assemblage in Upper Newport bay, California. Fisheries bulletin, 80(4).

Arntz W & Fahrbach E (1996) El Niño, experimento climático de la naturaleza. Fondo de la Cultura Económica, Mexico.

Blaize S & Lacoste D (1995): Atlas Climatique de la Nouvelle Calédonie. Météo-France, Nouméa, Nouvelle Calédonie, 104.

Bortone, S.A, Samoilys, M.A, Francour, P, (2000) Fish and macroinvertebrate evaluation. In: Seaman Jr., W. (Ed.), Artificial Reef Evaluation with application to Natural Marine Habitats. CRC Press, Boca Raton, 127–164.

Burt J, Bartholomew A, Usseglio P, Bauman A, Sale P.F (2009) Are articial reefs surrogates of natural habitats for coral and fish in Dubai, United Arab Emirates? Coral reefs 28, 663-675.

Claisse J.T, McTee S.A and Parrish J.D (2009) Effects of age, size and density on natural survival for an important coral reef fishery species, yellow tang, *Zebrasoma flavescens*. Coral reefs 28, 95-105.

Clark B.M, Bennett B.A, and Lamberth S.J (1996) Temporal variations in surf zone fish assemblages from False Bay, South Africa. Marine ecology progress series 131, 35-47.

Debenay J.P (1988) Foraminifera larger than 0.5 mm in the southwestern lagoon of New Caledonia; distribution related to abiotic properties. The journal of foraminiferal research 18(2), 158-175.

Gibson R, Robb L, Burrows M.T and Ansell A.D (1996) Tidal, diel and longer term changes in the distribution of fishes on a Scottish sandy beach. Marine ecology progress series 130, 1-17.

Glynn P.W (1988) El Niño-Southern Oscillation 1982-1983: near-shore population, community, and ecosystem responses. Annual Review Ecology System 19, 309-345.

Grimaud J & Kulbicki M (1998) Influence of reef to ocean distance on coral reef fish assemblages in New Caledonia. Life sciences, 321,923-931.

Grove J (1985) Infulence of the 1982-1983 El Niño event upont the ichthyofauna of the Galapagos archipelago. In: El Niño en la islas Galápagos: el event de 1982-1983. Fundación Charles Darwin, Quito, 191-198.

Harmelin-Vivien M.L, Harmelin J.G, Chauvet C, Duval C, Galzin R, Lejeune P, Barnabé G, Blanc F, Chevalier R, Duclerc J, Lasserre G (1985) Evaluation visuelle des peuplements et population de poissons: methodes et problemes. Revue d'écologie. (la Terre et la vie), 40.

Harvey E, Fletcher D and Shortis M (2002) Estimation of reef fish length by divers and by stereovideo: A first comparison of the accuracy and precision in the field on living fish under operational conditions. Fisheries research 57(3), 255-265.

Hawryshyn C.W, Moyer H.D, Allison T.E, Haimberger T.J and McFarland W.N (2003) Multidimensional polarization sensitivity in damselfishes. Journal of comparative physiology A 189, 2 13-220.

Kingsforad M & Finn M (1997): The influence of phase of the moon and physical processes on the input of presettlement fishes to coral reefs Journal of Fish Biology (51) (Supplement A), 176-205.

Langlois T.J, Anderson M.J, Babcock R.C and Kato S (2006) Marine reserves demonstrate trophic interactions across habitats. Oecologia 147(1), 134-140.

Langlois T.J, Harvey E.S, Fitzpatrick B, Meeuwig J.J, Shedrawi G, and Watson D.L (2010) Cost-efficient sampling of fish assemblages: comparison of baited video stations and diver video transects. Aquatic biology 157,1237–1250.

Lara N.E & Gonzalez E.A (2005) The relationship between reef fish community structure and environmental variables in the southern Mexican Caribbean. Journal of fish biology 53, 209-221.

Lasiak T.A (1984b) Structural aspects of the surf-zone fish assemblage at King's Beach, Algoa Bay, South Africa: long term fluctuations. Estuarine coastal and shelf science 18, 459-4.

Leech D.M, Boing W.J, Cooke S.L, Williamson C.E, and Torres L (2009): UV-enhanced fish predation and the differential migration of zooplankton in response to UV radiation and fish. Limnology and oceanography 54(4), 1152.

Lirman D (1999) Reef fish communities associated with Acropora Palmata: relationships to benthic attributes. Bulletin of Marine Science 65(1), 235–252.

MacKenzie B.R & Leggett W.C (1991) Quantifying the contribution of small-scale turbulence to the encounter rates between larval fish and their zooplankton prey: effects of wind and tide. Marine ecology progress series, 73, 149-160.

McClanahan T.R & Arthur R (2001) The effect of marine reserved and habitat on populations of east African coral reef fishes. Ecological applications, 11(2), 559–569.

Moore R.H (1975) Occurrence of tropical marine fishes at Port Aransas, Texas 1967-1973. Relation to see wind velocity. Compeia 170-172.

Mora C & OspõÂna A.F (2001) Tolerance to high temperatures and potential impact of sea warming on reef fishes of Gorgona Island tropical eastern Pacific. Marine biology 139: 765.

Mora C, Chittaro P.M, Sale P.F, Kritzer J.P ans Ludsin SA (2003) Patterns and processes in reef fish diversity. Nature 421, 933-936.

Morrison M.A, Francis M.P, Hartill B.W and Parkinson D.M (2002) Diurnal and tidal variation in the abundance of the fish fauna of a temperate tidal mudflat. Estuarine, coastal and shelf science 54, 793–807.

Myrick C.A & Cech J.J (2000) Temperature influences in California rainbow trout physiological performance. Fish physiology and biochemistry 22, 245-254.

Nagelkerken I, Dorenbosch M, Verberk W.C, De la Moriniere C.E and Van der Velde G (2000) Day-night shifts of fishes between shallow-water biotopes of a Caribbean bay, with emphasis on the nocturnal feeding of Haemulidae and Lutjanidae. Marine ecology progress series 194, 55–64.

Newman S.J & Williams McB (2001) Spatial and temporal variation in assemblages of Lutjanidae, Lethrinidae and associated fish species among mid-continental shelf reefs in the central Great Barrier Reef. Marine and freshwater research 52, 843–51.

Pauly D, Christensen V, Guénette S, Pitcher T.J, Rashid Sumaila U, Walters C.J, Watson R, Zeller D (2002) Towards sustainability in world fisheries. Nature 418, 689-695.

Pillay R.M, Terashima H, Venkatasami A, Uchida H (2002) Fiel guide to corals of Mauritius Albion fisheries research centre, ministry of fisheries.

Quinn T.M, Crowley T.J, Taylor F.W, Henin C, Joannot P, Join P (1998) A multicentury stable isotope record from a New Caledonia coral: Interannual and decadal sea surface wind velocity variability in the southwest Pacific since 1657 A.D. Paleoceanography 13(4), 412-426.

Samoilys, M.A (1997) Underwater visual census surveys. In: Samoilys, M. (Ed.), Manual for Assessing Fish Stocks on Pacific Coral Reefs. Department of Primary Industries, Townsville, Australia.

Santos RS & Nash R.D.M (1995) Seasonal changes in a sandy beach fish assemblage at Porto Pim, Faial, Azores-Estuarine. Coastal and shelf science.

Springer V.G & McErlean A.J (1962) A study of the behavior of some tagged south Florida Coral reef fishes. The American midland naturalist.

Stobart B, García-Charton J.A, Espejo C, Rochel E, Goñi R, Reñones O, Herrero A, Crec'hriou R, Polti S, Marcos C, Planes S, and Pérez-Ruzafa A (2007) A baited underwater video technique to assess shallow-water Mediterranean fish assemblages: Methodological evaluation. Journal of experimental marine biology and ecology 345, 158–174.

Tessier E, Chabanet P, Pothin K, Soria M and Lasserre G (2005) Visual censuses of tropical fish aggregations on artificial reefs: slate versus video recording techniques. Journal of experimental marine biology and ecology 315(1), 17-30

Tresher R.E, Gunn J.S, (1986) Comparative analysis of visual census techniques for highly mobile, reef associated piscivores (Carangidae). Environmental biology of fishes 17, 93–116.

Unsworth R.K.F, Bell J.J and Smith D.J (2007): Tidal fish connectivity of reef and sea grass habitats in the Indo-Pacific. Journal of marine biological association of the United Kingdom 87, 1287–1296.

Vera L.M, Davie A, Taylor J.F and Migaud H (2009): Differential light intensity and spectral sensitivities of Atlantic salmon, European sea bass and Atlantic cod pineal glands ex vivo. General and comparative endocrinology.

Watson D.L, Harvey E.S, Anderson M.J and Kendrick G.A (2005) A comparison of temperate reef fish assemblages recorded by three underwater stereo-video techniques. Marine biology 148(2), 415-425.

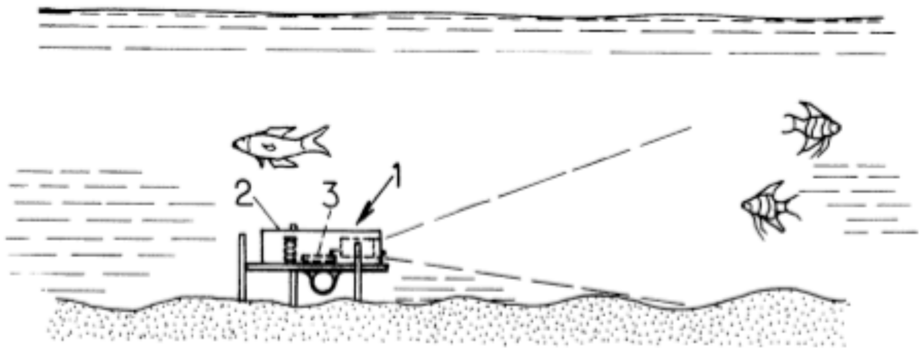
Watson D.L, Harvey E.S, Fitzpatrick B.M, Langlois T.J and Shedrawi G (2010): Assessing reef fish assemblage structure: how do different stereo-video techniques compare? Marine biology 157, 1237–1250.

Wilkinson C (2002) Status of coral reefs of the world**.**

Wilson S.K, Dolman A.M, Cheal A.J, Emslie M.J, Pratchett M.S and Sweatman H.P.A (2009) Maintenance of fish diversity on disturbed coral reefs. Coral Reefs 28(1) 3-14

Figures and Tables

Figure 1: Schema of the video system. 1:camera, 2:timer, 3:hard disk



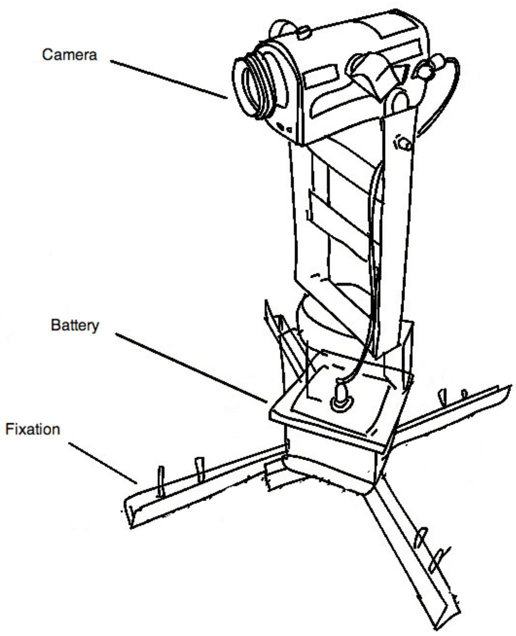


Table 1: Occurrence (Occ in %) number of species (S) and individuals (N) recorded per sequence and per day for each observed family.

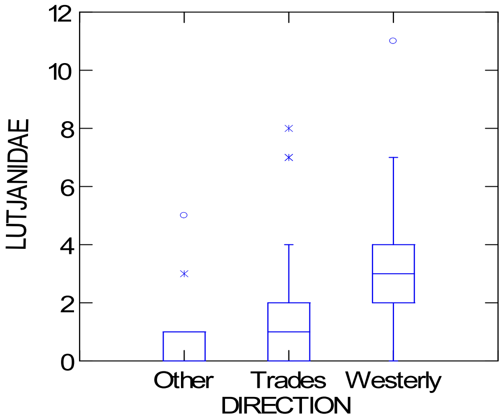
	Sequence							Day						
	Occ	S			N			Occ	S			N		
Family		Mean	Max	Min	Mean	Max	Min		Mean	Max	Min	Mean	Max	Min
Pomacentridae	99.3	2.4	(4 -	0)	79.4	(173 -	0)	100.0	2.9	(4 -	2)	79.8	(173 -	35)
Lethrinidae	92.2	1.2	(3 -	0)	5.5	(27 -	0)	100.0	2.0	(4 -	1)	5.4	(27 -	2)
Labridae	86.1	1.3	(4 -	0)	4.2	(14 -	0)	100.0	3.7	(7 -	1)	8.2	(16 -	1)
Siganidae	81.3	1.2	(4 -	0)	3.6	(51 -	0)	100.0	3.0	(5 -	1)	27.0	(73 -	2)
Acanthuridae	78.5	1.3	(5 -	0)	2.1	(22 -	0)	100.0	4.1	(7 -	1)	15.9	(34 -	2)
Scaridae	67.9	1.1	(6 -	0)	1.7	(17 -	0)	100.0	3.6	(7 -	1)	13.2	(34 -	1)
Chaetodontidae	65.9	1.2	(5 -	0)	1.6	(10 -	0)	100.0	4.8	(8 -	1)	12.0	(30 -	3)
Serranidae	46.0	0.6	(4 -	0)	0.7	(5 -	0)	99.0	3.0	(5 -	0)	5.0	(13 -	0)
Haemulidae	24.0	0.3	(2 -	0)	0.3	(4 -	0)	80.4	1.1	(2 -	0)	2.6	(11 -	0)
Lutjanidae	19.2	0.2	(2 -	0)	0.4	(11 -	0)	66.0	0.8	(3 -	0)	3.0	(23 -	0)
Diodontidae	12.9	0.1	(1 -	0)	0.1	(2 -	0)	45.4	0.5	(1 -	0)	1.0	(6 -	0)
Pomacanthidae	5.1	0.1	(1 -	0)	0.1	(1 -	0)	36.1	0.4	(1 -	0)	0.4	(3 -	0)
Mullidae	4.2	0.0	(1 -	0)	0.1	(4 -	0)	29.9	0.3	(2 -	0)	0.4	(4 -	0)
Balistidae	4.1	0.0	(1 -	0)	0.0	(1 -	0)	24.7	0.3	(1 -	0)	0.3	(2 -	0)
Carangidae	2.2	0.0	(1 -	0)	0.0	(2 -	0)	16.5	0.2	(1 -	0)	0.2	(2 -	0)
Monacanthidae	1.2	0.0	(1 -	0)	0.0	(2 -	0)	9.3	0.1	(1 -	0)	0.1	(2 -	0)
Caesionidae	1.0	0.0	(1 -	0)	0.0	(26 -	0)	6.2	0.1	(1 -	0)	0.6	(26 -	0)
Tetraodontidae	0.7	0.0	(2 -	0)	0.0	(2 -	0)	4.1	0.1	(2 -	0)	0.1	(2 -	0)
Inconnu	0.3	0.0	(1 -	0)	0.0	(1 -	0)	2.1	0.0	(1 -	0)	0.0	(1 -	0)
Carcharhinidae	0.1	0.0	(1 -	0)	0.0	(1 -	0)	1.0	0.0	(1 -	0)	0.0	(2 -	0)
Gobiidae	0.1	0.0	(1 -	0)	0.0	(1 -	0)	1.0	0.0	(1 -	0)	0.0	(3 -	0)
Murenidae	0.1	0.0	(1 -	0)	0.0	(1 -	0)	1.0	0.0	(1 -	0)	0.0	(4 -	0)
Myliobatidae	0.1	0.0	(1 -	0)	0.0	(1 -	0)	1.0	0.0	(1 -	0)	0.0	(5 -	0)
Nemipteridae	0.1	0.0	(1 -	0)	0.0	(1 -	0)	1.0	0.0	(1 -	0)	0.0	(6 -	0)

Table 2: Output from the GLM by step Hwater= mean of height of water per day (metre), Lambda= Max of height of water per day minus min of height of water (metre), Velocity=strength of the wind (m s^{-1}), Direction= daily direction of the wind (offshore, along shore and other winds), Solar= light intensity (J cm^{2-1}), Tlagoon= daily average of the lagoon wind velocity. (P-value: *<0.05, **<0.01, ***<0.001) > increase, < decrease, Off: offshore wind, Along: along shore wind, Oth: other wind

N	Hwater	Lambda	Velocity	Direction	Solar	Tlagoon	H*L	R² (%)
Lethrinidae	> *	> **	-	Al-Oth *	> *	> **	> **	49.8
Labrid juv	< *	< **	< **	-	< **	< ***	< *	31.2
Pomacentridae	-	-	< ***	-	< ***	-	-	28.9
Lutjanidae	-	< **	-	Off **	-	-	< ***	28.7
Acanthuridae	-	< ***	-	-	-	-	< ***	15.0
Labridae	-	-	-	-	-	> *	-	11.6
Chaetodontidae	-	< *	-	-	-	-	-	7.7
Haemulidae	-	-	-	-	< **	-	-	7.0
Siganidae	-	< *	-	-	-	-	-	4.0
Scaridae	-	-	-	-	-	-	-	-
Serranidae	-	-	-	-	-	-	-	-

Figure 2: Abundance per day of Lethrinidae and Lutjanidae in function of Wind direction: Other (wind with an other direction), Trade (onshorealong shore wind), Westerly (offshore wind). 1st line= 1st quartile, 2nd line= median, 3rd line= 3rd quartile

a)



b)

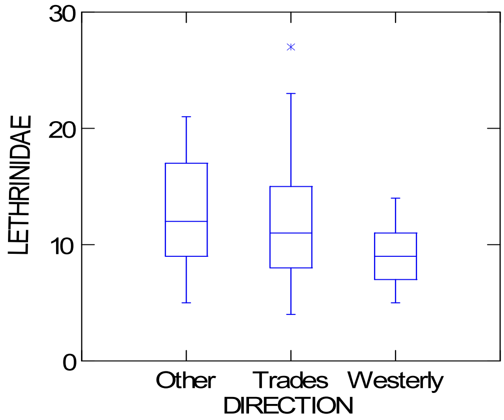


Table 3: Comparison of the cost for similar sampling campaigns of 300 days, seven samples per days, performed with traditional underwater visual census method (UVC) and the video system used in this study.

	UVC	Video system
Number of dives	300 * 7	12
Cost per year	185 000 $	12 000 $
Cost per day	600 $	35 $
Total time for obtaining and processing the information	25 min	7 min

ANNEXE 1: List of recorded species: Mean, maximum (Max) and minimum (Min) of abundance (N) and occurrence (Occ) were estimated per day and per sequence for each species.

			Sequence				Day			
			Occ	N			Occ	N		
Genus	Species	Familly		Mean	Max	Min		Mean	Max	Min
Acanthurus	*albipectoralis*	Acanthuridae	0.7	0	(3 -	0)	5.0	0.1	(3 -	0)
Acanthurus	*sp*	Acanthuridae	0.5	0	(2 -	0)	4.1	0.1	(2 -	0)
Acanthurus	*blochii*	Acanthuridae	5.4	0.1	(2 -	0)	32.0	0.5	(4 -	0)
Acanthurus	*dussumeri*	Acanthuridae	0.7	0	(1 -	0)	5.2	0.1	(1 -	0)
Acanthurus	*nigricauda*	Acanthuridae	32.6	0.5	(16 -	0)	91.8	4.1	(21 -	0)
Aetobatis	*narinari*	Myliobatidae	0.1	0	(1 -	0)	1.0	0.0	(1 -	0)
Aluterus	*scriptus*	Monacanthidae	1.1	0	(1 -	0)	8.2	0.1	(1 -	0)
Amblyeleotris	*sp*	Gobiidae	0.1	0	(1 -	0)	1.0	0.0	(1 -	0)
Anyperodon	*leucogrammicus*	Serranidae	3.9	0	(2 -	0)	25.8	0.3	(3 -	0)
Arothron	*stellatus*	Tetraodontidae	0.4	0	(1 -	0)	2.1	0.0	(2 -	0)
Balistoides	*sp*	Balistidae	0.1	0	(1 -	0)	1.0	0.0	(1 -	0)
Balistoides	*viridescens*	Balistidae	3.9	0	(1 -	0)	23.7	0.3	(2 -	0)
Bodianus	*perditio*	Labridae	5	0.1	(1 -	0)	36.1	0.4	(2 -	0)
Canthigaster	*sp*	Tetraodontidae	0.4	0	(1 -	0)	3.1	0.0	(1 -	0)
Caranx	*melampygus*	Carangidae	2	0	(1 -	0)	15.5	0.2	(1 -	0)
Casio	*cuning*	Caesionidae	0.9	0.1	(26 -	0)	6.2	0.6	(26 -	0)
Cephalopholis	*argus*	Serranidae	2.4	0	(1 -	0)	14.4	0.2	(3 -	0)
Chaerodon	*graphicus*	Labridae	15.4	0.2	(4 -	0)	73.2	1.4	(6 -	0)
Chaeteodon	*lunulatus*	Chaetodontidae	8.1	0.1	(2 -	0)	42.3	0.8	(6 -	0)
Chaetodon	*auriga*	Chaetodontidae	6.2	0.1	(2 -	0)	39.2	0.6	(3 -	0)
Chaetodon	*ephippium*	Chaetodontidae	8.8	0.1	(2 -	0)	48.5	0.8	(4 -	0)
Chaetodon	*flavirostris*	Chaetodontidae	24.5	0.4	(3 -	0)	86.6	2.8	(11 -	0)
Chaetodon	*lineaolatus*	Chaetodontidae	30.6	0.4	(5 -	0)	90.7	3.4	(11 -	0)
Chaetodon	*speculum*	Chaetodontidae	26	0.4	(6 -	0)	86.6	2.7	(11 -	0)
Chaetodon	*ulietensis*	Chaetodontidae	3.2	0	(2 -	0)	19.6	0.3	(3 -	0)
Chaetodon	*vagabundus*	Chaetodontidae	1.4	0	(2 -	0)	10.3	0.1	(2 -	0)
Cheilinus	*chlorurus*	Labridae	3.5	0	(1 -	0)	21.7	0.3	(2 -	0)
Chlorus	*sordidus*	Scaridae	2.3	0	(2 -	0)	12.4	0.2	(3 -	0)
Chromis	*viridis*	Pomacentridae	98.8	68.9	(162 -	0)	100.0	69.2	(162 -	30)
Coradion	*altivelis*	Chaetodontidae	3.7	0	(1 -	0)	22.7	0.3	(3 -	0)
Cromileptes	*altivelis*	Serranidae	10.4	0.1	(2 -	0)	45.4	0.9	(5 -	0)
Ctenochaetus	*striatus*	Acanthuridae	54.4	0.9	(10 -	0)	100.0	7.2	(23 -	1)
Diodon	*hystrix*	Diodontidae	12.9	0.1	(2 -	0)	45.4	1.0	(6 -	0)
Diploprion	*Bifaciatum*	Serranidae	16.9	0.2	(4 -	0)	81.4	1.5	(5 -	0)
Epibulus	*insidiator*	Labridae	4.9	0.1	(2 -	0)	26.8	0.4	(3 -	0)
Epinephelus	*coeruleopunctatus*	Serranidae	1.4	0	(1 -	0)	7.2	0.1	(4 -	0)
Epinephelus	*howlandi*	Serranidae	0.1	0	(1 -	0)	1.0	0.0	(1 -	0)
Epinephelus	*polyphekadion*	Serranidae	9.6	0.1	(2 -	0)	54.6	0.8	(4 -	0)
Gnathanodon	*speciosus*	Carangidae	0.1	0	(2 -	0)	1.0	0.0	(2 -	0)
Gymnothorax	*javanicus*	Murenidae	0.1	0	(1 -	0)	1.0	0.0	(1 -	0)
Hemigymnus	*fasciatus*	Labridae	0.1	0	(1 -	0)	1.0	0.0	(1 -	0)
Hemigymnus	*melapterus*	Labridae	7.3	0.1	(2 -	0)	45.4	0.6	(3 -	0)
Heniochus	*acuminatus*	Chaetodontidae	1.1	0	(3 -	0)	7.2	0.1	(3 -	0)
Heniochus	*monoceros*	Chaetodontidae	4.1	0	(2 -	0)	28.9	0.3	(3 -	0)
Hipposcarus	*longiceps*	Scaridae	9.9	0.1	(8 -	0)	46.4	1.1	(9 -	0)
Inconnu	*Inconnu*	Inconnu	0.3	0	(1 -	0)	2.1	0.0	(1 -	0)
Labre	*juvénil*	Labridae	77.8	3.6	(13 -	0)	97.9	3.6	(13 -	0)

Labroides	*dimidiatus*	Labridae	0.3	0	(2 - 0)	2.1	0.0	(2 - 0)
Lethrinus	*atkinsoni*	Lethrinidae	90.1	4.9	(23 - 0)	100.0	37.2	(83 - 8)
Lethrinus	*obsoletus*	Lethrinidae	1.1	0	(1 - 0)	7.2	0.1	(2 - 0)
Lethrinus	*olivaceus*	Lethrinidae	0.5	0	(5 - 0)	4.1	0.1	(5 - 0)
Lutjanus	*argentimaculatus*	Lutjanidae	0.3	0	(3 - 0)	2.1	0.0	(3 - 0)
Lutjanus	*bohar*	Lutjanidae	0.9	0	(1 - 0)	7.2	0.1	(1 - 0)
Lutjanus	*fulvus*	Lutjanidae	16.5	0.4	(11 - 0)	58.8	2.7	(23 - 0)
Lutjanus	*rivulatus*	Lutjanidae	0.3	0	(1 - 0)	2.1	0.0	(1 - 0)
Lutjanus	*russellii*	Lethrinidae	25.7	0.6	(7 - 0)	81.4	4.2	(19 - 0)
Macolor	*niger*	Lutjanidae	1.4	0	(2 - 0)	10.3	0.1	(2 - 0)
Monotaxis	*grandoculis*	Lethrinidae	1.4	0	(2 - 0)	9.3	0.1	(3 - 0)
Naso	*brevirostris*	Acanthuridae	11	0.2	(4 0)	53.6	1.2	(10 - 0)
Naso	*unicornis*	Acanthuridae	7	0.1	(3 - 0)	37.1	0.6	(5 - 0)
Neoglyphidodon	*melas*	Pomacentridae	39.8	0.5	(3 - 0)	87.6	4.0	(9 - 0)
Parupeneus	*barberinus*	Mullidae	3.2	0	(4 - 0)	23.7	0.3	(4 - 0)
Parupeneus	*indicus*	Mullidae	0.9	0	(2 - 0)	7.2	0.1	(2 - 0)
Pervagor	*janthinosoma*	Monacanthidae	0.1	0	(2 - 0)	1.0	0.0	(2 - 0)
Plectorhinchus	*chaetodonoides*	Haemulidae	21.1	0.3	(4 - 0)	78.4	2.1	(11 - 0)
Plectorhinchus	*lineatus*	Haemulidae	3.8	0	(1 - 0)	20.6	0.3	(3 - 0)
Plectorhinchus	*vittatus*	Haemulidae	1.5	0	(1 - 0)	7.2	0.1	(3 - 0)
Plectropomus	*leopardus*	Serranidae	13.8	0.2	(3 - 0)	63.9	1.2	(7 - 0)
Pomacanthus	*sexstriatus*	Pomacanthidae	5.1	0.1	(1 - 0)	36.1	0.4	(3 - 0)
Pomacentrus	*coelestis*	Pomacentridae	0.3	0	(1 - 0)	2.1	0.0	(1 - 0)
Pomacentrus	*Moluccencis*	Pomacentridae	98.5	10.1	(18 - 0)	100.0	10.0	(14 - 6)
Scarus	*sp*	Scaridae	0.8	0	(2 - 0)	5.2	0.1	(3 - 0)
Scarus	*frenatus*	Scaridae	0.1	0	(1 - 0)	1.0	0.0	(1 - 0)
Scarus	*ghobban*	Scaridae	42.6	0.6	(6 - 0)	99.0	4.5	(12 - 0)
Scarus	*microrhinos*	Scaridae	5.4	0.1	(2 - 0)	34.0	0.5	(5 - 0)
Scarus	*niger*	Scaridae	5.1	0.1	(2 - 0)	29.9	0.4	(3 - 0)
Scarus	*psittacus*	Scaridae	2.6	0	(2 - 0)	16.5	0.2	(3 - 0)
Scarus	*rivulatus*	Scaridae	36.7	0.8	(15 - 0)	96.9	6.0	(23 - 0)
Scarus	*schlegeli*	Scaridae	3.1	0	(2 - 0)	19.6	0.3	(2 - 0)
Scolopsis	*bilineatus*	Nemipteridae	0.1	0	(1 - 0)	1.0	0.0	(1 - 0)
Serranidae	*sp*	Serranidae	0.3	0	(1 - 0)	2.1	0.2	(3 - 0)
Siganus	*argenteus*	Siganidae	0.3	0	(1 - 0)	2.1	0.0	(1 - 0)
Siganus	*doliatus*	Siganidae	26.3	0.5	(8 - 0)	87.6	0.0	(1 - 0)
Siganus	*fuscescens*	Siganidae	2.4	0.1	(32 - 0)	15.5	3.7	(13 - 0)
Siganus	*sp*	Siganidae	0.1	0	(1 - 0)	1.0	1.0	(32 - 0)
Siganus	*lineatus*	Siganidae	67.3	2.5	(22 - 0)	99.0	0.0	(1 - 0)
Siganus	*punctatus*	Siganidae	17.2	0.3	(6 - 0)	81.4	19.1	(63 - 0)
Siganus	*rivulatus*	Siganidae	2	0.1	(47 - 0)	15.5	2.2	(11 - 0)
Symphorichthys	*spirals*	Lutjanidae	0.1	0	(1 - 0)	1.0	1.0	(47 - 0)
Thalassoma	*lunare*	Labridae	12.9	0.2	(9 - 0)	63.9	0.0	(1 - 0)
Triaenodon	*obesus*	Carcharhinidae	0.1	0	(1 - 0)	1.0	1.5	(9 - 0)
Zebrasoma	*scopa*	Acanthuridae	0.7	0	(1 - 0)	5.2	0.0	(1 - 0)
Zebrasoma	*veliferum*	Acanthuridae	16.1	0.3	(15 - 0)	73.2	0.0	(1 - 0)