Reef and lagoon fisheries yields in Moorea: A summary of data collected

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Introduction

Due to their diversity of animal and plant species, coral reefs are among of the most productive and complex marine ecosystems in the world (Birkeland 1997; Grigg et al. 1984; Letourneur and Chabanet 1994). Covering a surface area of 255,000 km^2 (Spalding and Grenfell 1997), coral reefs support the development of local and national economies and provide a large number of goods and services to island communities through fisheries and tourism (Moberg and Folke 1999).

Exploiting reef ecosystems and their resources, including fisheries, is of major importance to many Pacific Island countries and peoples, especifically those in the South Pacific (Ferraris and Cayré 2003; Kronen 2007). These largely small-scale fisheries call on a variety of fishing strategies (e.g. commercial fishing, recreational fishing, subsistence fishing). These multi-species and multi-gear fisheries and their widely scattered landing sites, do not facilitate the task of collecting reliable data to quantify such activities (Ferraris and Cayré 2003). Total artisanal fishery production[4] in the South Pacific has been estimated at 100,000 t, with significant disparities between islands. In addition, some 80% of these landings come from subsistence fisheries activities (Dalzell et al. 1996). The absence of any large single-species stock, the difficulty that fishing vessels have in gaining access to coral reefs, and the possibility of ciguatera on certain islands explain why reef fisheries are mainly artisanal or traditional.

Given that fishing activities in French Polynesia are widely dispersed, it is extremely difficult to get accurate catch figures. Current statistical data are not reliable because these figures cover inter-island air transport but do not include subsistence and recreational fisheries. While only limited statistics exist on lagoon products, French Polynesia's total production can be estimated at about 4,300 t annually (SPE 2006). Production is thought to be distributed as follows: 3,400 t of lagoon fish, 700 t of small pelagic fish, and 200 t of other types of catch (e.g. molluscs, crustaceans, echinoderms).

Artisanal fisheries are an integral part of the French Polynesian lifestyle. They are roughly divided into three categories: oceanic fisheries, coastal fisheries and lagoon fisheries. Lagoon and/or reef fisheries, which are the focus of this article, can be described as "all the activities that are involved in exploiting biological resources and are carried out on the fringing and barrier reefs, channels, passes and *hoa* (or lagoon in the widest sense) and on the first few metres of the outer slope (depths <80 to 100 m) to the very limits of coral growth" (Galzin et al. 1989; SPE 2006).

Fishing activities on Moorea are important socio-economically because they provide income from fish sales as well as food security[5] (home consumption) (Aubanel 1993). Moorea has experienced very high population growth over the past 36 years. Population census figures for Moorea went from 5,058 to 16,490 between 1971 and 2007 (ISPF 2007) — an annual population growth rate of 2.39%, which is higher than the rate for French Polynesia as a whole (1.57%). In addition, elsewhere in the Pacific Islands, fishing pressure is directly linked to the number of inhabitants (Jennings and Kaiser 1998; Russ and Alcala 1989). Given these demographics and growing urbanisation, it is vital to get a precise picture of Moorea's fisheries activities. A large number of studies since 1985 have attempted to assess fish production[6] (Galzin 1985) or reef and lagoon fisheries yields[7] (Aubanel 1993; Brenier 2009; Vieux 2002; Yonger 2002) on Moorea. As in other coral island settings, quantifying lagoon fisheries here has proven to be a particularly difficult exercise for many reasons. Fishing is often done at night (with or without a boat), is widely dispersed, uses many different types of gear, and landings and sales do not take place at specific sites but rather anywhere along the coast and often even on private stretches of coastline on family properties (Fig. 1).

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[4] Total catches by a fishery over a year (given in tonnes).
[5] Part of the fishery catches are destined for home consumption within the family.
[6] Fish biomass (in tonnes).
[7] Reef and lagoon fisheries yield corresponds to the fishery production of all lagoon fishing activities, which is expressed in the form of yield (i.e. catches in tonnes per surface area unit, or km^2, over a period of time, generally one year). It is also called fisheries performance.

Figure 1. Lagoon fish sold along the roadside on Moorea (Images: R. Madi Moussa).

Research methodologies used between the times of Galzin (1985) and Brenier (2009) have also evolved considerably. Over the space of 25 years, five different studies attempted to evaluate Moorea's lagoon fishery production (in the form of yield), and only two studies (Aubanel 1993 and Vieux 2002) used the same methodology. Fishery production estimates for Moorea's lagoon vary widely from one study to the next — even more so depending on the methodology used. The goal of this study is to review studies conducted over the past 25 years that describe lagoon fishing activities in Moorea. Special attention is paid to examining the limits of the various estimation methods used in each study so as to decide which lagoon fishery production estimate seems to be the most realistic.

Materials and methods: Characterising lagoon fisheries activities on Moorea and reviewing the various methods used for estimating fishery production

Study site

Moorea lies 25 km northwest of Tahiti (17°30' S, 149°50' W). Triangular in shape, the island covers a surface area of 134 km^2, with a maximum elevation of 1,207 m (Mount Tohivea), and has a 61-km-long coastline (Fig. 2).

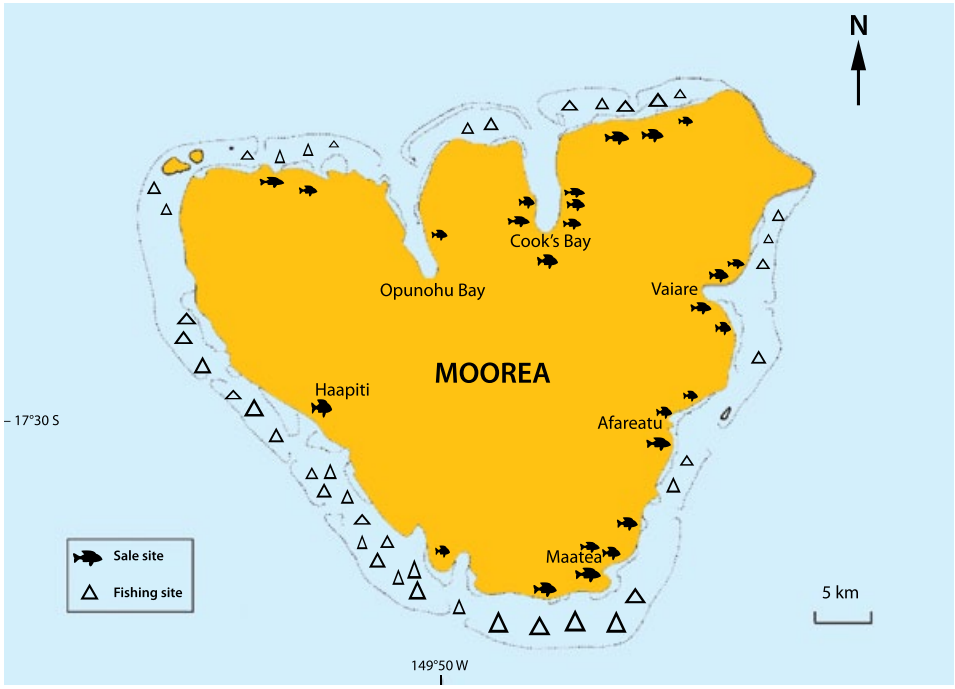

Figure 2. Moorea's fishing and landing sites.

The island is surrounded by a barrier reef that encloses a 49 km^2 lagoon, whose width varies from 500 m to 1,500 m, with depths of 0.5–30 m. The barrier reef has 11 passes that vary in depth (Galzin 1985). The entire coral ecosystem remains submerged at low tide and the tidal range is only about 40 cm. Moorea has a moist tropical climate with two distinct seasons — a hot rainy season from November to April and a cool, less rainy season from May to October. Moorea has a marine area management plan (PGEM), the first in French Polynesia, which applies to the township of Moorea by Order no. 410/CM dated 21 October 2004. The PGEM has four objectives: 1) rational use and development of resources and the area; 2) managing conflicts regarding lagoon use; 3) controlling pollution and damage to marine environments; and 4) protecting marine ecosystems and endangered species.

Moorea's lagoon fisher population

According to Yonger (2002), Brenier (2009) and Leenhardt (2009), there are three categories of fishers on Moorea: commercial fisher, subsistence fisher and recreational fisher (Table 1).

In all, 23.2% of Moorea's population is involved in fishing: 16% for recreational purposes, 4.6% for supplementary income (subsistence) and 2.6% are commercial fishers (Brenier 2009; Leenhardt 2009; Yonger 2002). While commercial and subsistence fishers are all Moorea residents, a certain number of recreational fishers come from the nearby Society Islands, mainly Tahiti (Leenhardt 2009). It should be noted that more than 70% of the people who fish on Moorea are recreational fishers. None of the catches from this category of fisher appear in the fisheries data collected at landings or at sales sites. Moreover, according to Yonger (2002), subsistence fishing may account for 58% of the catches in the lagoon. Also, a percentage of those catches are never recorded because they are directly destined for home consumption.

Lagoon fisheries techniques

The extremely wide diversity of lagoon catches explains why there are so many fishing techniques, each adapted to very specific organisms. Given the many different techniques, fishers often use a multidisciplinary approach, using several techniques depending on their preferences and resources, season, weather conditions, target species, and time of day. The main gear types used in the lagoon are spearguns, nets (gillnets or nets with pot traps), lines (handlines, hook-and-line, trolling, bottom longlines), harpoons, beach seines, cast nets or scoop nets (Leenhardt 2009; Yonger 2002). Fish traps, which are widely used in the Tuamotu and Leeward Islands, and account for 90% of catches in those areas (Galzin et al. 1989), are not used in Moorea's lagoon.

a. Net fishing

Net fishing is commonly used on Moorea and takes a wide variety of forms: gillnet fishing; beach seine net fishing (used seasonally on bay floors to catch *ature*, or *Selar crumenophthalmus)*; funnel net fishing (*haapua*), which includes a wire net that targets parrotfish, trevallies, surgeonfish and goatfish; cast nets and scoop nets, which are used to catch flyingfish.

b. Speargun fishing

This technique is widely used on Moorea, both during the day and at night with a powerful electric torch. When this type of fishing is done at night, it is very effective, providing high yields per fishing trip. This technique accounts for about 29% of lagoon fish production in the Windward Islands as compared with 18% in the Leeward Islands (SPE 2006). This type of fishing is very selective but can lead to local overexploitation of stocks because so many species (80%) are non-migratory and tend to be confined to a specific habitat (Lecaillon et al. 2000).

c. Line fishing

Line fishing is done directly from the coastline or from vessels powered by oars or 2–25 hp outboard motors. The different techniques include trolling, bottom longlining, fishing with artificial lures, using lines with one or more hooks, and fishing with natural and live bait.

d. Pot and trap fishing

This technique mainly targets fish but also crabs and other crustaceans.

Table 1. Classification and characteristics of fishers on Moorea.

Commercial fisher	Subsistence fisher	Recreational fisher
Two to five fishing trips per week	One to three trips per week	One to four trips per month
Sells catch	Some of the catch is sold and some is kept for home consumption	Catch is for home consumption
Fishing is the main source of income for the year	Fishing is a supplementary form of income	Fishing is primarily a recreational activity

An overexploited lagoon?

Results of perception surveys by Brenier in 2009 clearly indicate that Moorea has experienced a decline in the abundance and size of food fish species, increased scarcity of giant clams, decreased live coral cover, and increased macroalgae cover. By extrapolating these data, he also estimated the fisher population at 77 fishers km^{-2}, with 1,916 ± 530 motor boats and 481 ± 68 fishing trips km^{-2} each month. The latter figures show the intensity of fishing pressure on Moorea's coral ecosystems and are potential indicators of overexploitation. Fishing pressure can be considered high with 5 fishers km^{-2} (McClanahan et al. 2002).[8] These observations by the local population are potential signals of the overexploitation of lagoon resources.

Women gillnet fishing in Moorea's lagoon (Image: R. Madi Moussa).

In addition, in 2005, using underwater surveys Lison de Loma noted a decrease in the size of herbivores. In 2008, several photo identification campaigns involving lagoon fish catches sold along the roadside clearly confirmed a decrease in the size of all marketable fish (Madi Moussa 2010). In addition, most catches are taken with spearguns, a type of gear that is very selective. It would be reasonable to think that each fisher tries to maximise the sizes of catches so as to optimise profits. So the size ranges of the marketable species sold on the roadside represent the maximum size values for fish that can be caught by spearfishing. They are, therefore, good indicators of the maximum fish sizes found in the lagoon. Also, while over the past decade, most fishers say that they are still catching as many fish, they all agree that their fishing effort has increased (Leenhardt 2009). All of these perception indicators and field data tend to confirm the idea that Moorea's lagoon is overexploited.

Estimation methodologies

The maximum sustainable yield[9] (MSY) calculations that Galzin (1985) used were based on fish production data obtained by monitoring the three main species in Moorea's lagoon — the herbivorous fish *Ctenochaetus striatus*, the omnivorous fish *Stegastes nigricans* and the carnivorous fish *Sargocentron microstoma* — and extrapolated to total biomass along with the reef and lagoon fisheries production estimate that Munro made in 1984. Even though this MSY figure is more than 25 years old, it is worth using it because it is the only estimate done on Moorea. It served as a comparison for the orders of magnitude of fishery production estimates from the many studies that followed, and allowed comparisons between regions (Labrosse et al. 2000).

In order to assess lagoon fisheries yields, several estimating methods were used on Moorea, including such indicators as catches, tax on fish sold at the Paopao market, counting the number of fish sold on the roadside, and even house consumption data for the island. The results differed from one method to the next, often with very high ranges. However, the data from these methods provided information on fishers' catches and helped discern fishing pressure.

[8] It should be pointed out that the fishers listed were not all commercial fishers, who account for only 1% of the population, as the others were semi-commercial (6% of Moorea's population) and recreational fishers (17% of Moorea's population) (Brenier 2009).

[9] Maximum sustainable yield (MSY) is the largest quantity of biomass that can be removed from a fishery stock on average over the long-term under existing environmental conditions without affecting the reproduction process.

a. Estimating biomass and MSY

In 1985, Galzin studied the population dynamics (biology, biometry, stock, biomass, growth, production) of the three species and the different trophic levels in order to assess fish production in a reef and lagoon sector in northwest Moorea. These three species account for 74% of the total fish biomass of the fringing reef at the edge of the channel. The total biomass and the biomass for those three species were estimated at 103.4 g m^{-2} and 74.2 g m^{-2} $year^{-1}$. Those figures made it possible to calculate MSY (Y_{MAX}).

$Y_{MAX} = X\,(Y + MB)$

Y_{MAX} = maximum sustainable yield (MSY)

X = correction factor = 0.3 (Galzin 1985)

Y = annual fisheries yield = 10 t km^{-2} (Munro 1985)[10]

M = natural mortality

B = mean biomass

F = fisheries-related mortality = Y/B (Munro 1985)

Z = total mortality = $M + F = P/B$ (Munro 1985)

P = biological production

Z = P/B = 74.2 / 103.4 = 0.72

F = Y/B = 10/103.4 = 0.09

M = $Z - F$ = 0.72 - 0.09 = 0.63

Y_{MAX} = 0.3 (10 + (0.63 x 103.4)) = 23

Y_{MAX} = 23 t km^{-2} $year^{-1}$

b. Galzin's initial approach in 1985: the PaoPao market tax

Built in 1987, the Paopao market was the single official point of sales where, theoretically, all fishers from the north side of the island had to sell their fish, following an order that no longer authorised the sale of fish from along the roadside[11] (Aubanel 1993). According to observations and studies by Galzin et al. in 1989, total catches were roughly estimated at 7 t during November. This estimate was based on the fact that the township levied a tax of XPF 10 per kilo sold. Based on total catches for November, excluding pelagic fish, a figure for tonnage per production year was obtained.

c. Survey of roadside fish sales

In 1993 Aubanel, estimated Moorea's fishery production by inventorying *tui*[12] (Fig. 1) sold along the roadside and at the Paopao market. The weight was estimated by extrapolating the number of *tui* sold each year and multiplying the number of *tui* by 3 kg (the average weight of a *tui*). In 2002, Vieux repeated the same protocol to characterise lagoon fisheries and measure quantitative changes in this activity.

d. Consumption survey

In 2002, Yonger proposed a study based on a household lagoon-fish consumption survey to assess fishery production. An analysis of seafood consumption can be a good alternative for indirectly assessing fishery production (Gilbert 2006; Labrosse and Letourneur 1998; Labrosse et al. 2000; Loubens 1975; Paddon 1997). To be valid, this method requires that the case study be a well-defined system with low quantities of imported or exported reef and lagoon fish. On Moorea, it can be seen that catch exports are limited to recreational fishers who come over from Tahiti on the weekends. Fish imports are also relatively low and correspond to the sales of some pelagic fish (*ature*) from Tahiti or coolers sent from the Tuamotu Islands (Leenhardt 2009). In general, Moorea can be considered to be a virtually closed system because lagoon fish imports and exports have been deemed negligible (Brenier 2009). In all, 136 households were sampled (i.e. 4.9% of Moorea's household population).

As a comparison, a survey had just been carried on a village on Moorea. In 2006 Kronen conducted a socioeconomic survey in the township of Maatea in southern Moorea for the PROCFish project[13]. Of the 235 households in the township, 28 households (12%) with 112 people were surveyed and interviewed. This sample provided socioeconomic data on 25 fishers in the township (i.e. nearly 8.5% of the total presumed number of fishers in the township). Kronen precisely described the fisher population, particularly its composition (i.e. 18% commercial fishers, 11% subsistence fishers and 71% recreational fishers).

[10] Munro (1985) gave a figure of 15 t km^{-2} $year^{-1}$ for all fish, crustaceans and molluscs, and Russ and Alcala (1989) gave yields of 0.4 to 40 t km^{-2} $year^{-1}$ for fish in small areas of active coral growth (Yonger 2002).

[11] Since 1989, because the order is no longer applied several sales sites have reappeared around the island.

[12] A wreath of fish consisting of one or more species, tied together with plant fibre drawn through their gills and then suspended on a metal holder, which forms the sales unit.

[13] The Pacific Regional Oceanic and Coastal Fisheries (PROCFish) project was funded by the European Development Fund (EDF) and implemented by the Secretariat of the Pacific Community (SPC). The project was initiated in March 2002. The coastal component of PROCFish was designed to enhance management of reef fisheries in the Pacific Islands by providing Pacific Island governments and communities with accurate, unbiased scientific information about the status and prospects of reef fisheries. Seventeen countries and territories were targetted by the project.

e. Participatory method

Brenier carried out the most recent survey designed to estimate (indirectly) the fishery production of Moorea lagoon in 2009. It was based on participatory monitoring of reef fisheries through household surveys that were designed to collect data on consumption and fishing activity from large sample groups. Fishery production was estimated using surveys by schoolchildren, which provided detailed information on the fishing trips of one fisher in the household over a two-week period.

There were three or four parts to the questionnaire distributed to schoolchildren. The first part was designed to gather general information on the household's fishing activities and fish consumption (e.g. address and size of household, how often fish was eaten, origin of the fish eaten, number of boats, number of fishers). The second part included questions on the number of fishing trips of one fisher in the household over a two-week period (so as to cover one spring tide period and one neap tide period) along with the names, sizes and number of fish eaten at meals over the previous three days. These surveys involved 137 participants (i.e. 4.4% of household population), and the questionnaire return rate was 68%. The schoolchildren received training in how to carry out the survey in their homes using one questionnaire each.

Results: Overview of various fishery production estimates for Moorea

Reef and lagoon fisheries yield estimates for Moorea vary greatly from one estimation methodology to another (Table 2), and there is considerable differences in their approaches. Yield estimates based on catch data give us relatively low figures for the island's fisheries yields (from 0.7–2.2 t km^{-2} year^{-1}). On the other hand, data from consumption surveys or participatory surveys estimate fishing yields at between 20 t km^{-2} year^{-1} and 25 t km^{-2} year^{-1}.

Discussion

The significant differences noted between catch monitoring methods and those for socioeconomic surveys incite us to discuss the various limitations of each study so as to give our views on which lagoon fishery production estimate seems to be the most realistic.

Monitoring catches, landings and sales

An analysis of the methods used by Galzin, Aubanel and Vieux indicate that fishery production was underestimated, mainly because catches from recreational fishing and the quantities commercial and subsistence fishers ate themselves were not counted. In general, these studies demonstrated the difficulty in monitoring fishing activities in peri-urban island settings. The increase in population, the emergence of new markets (e.g. direct sales based on advance orders), and the discontinued use of the Paopao central market make it increasing difficult to monitor fish landings and estimate fishing production using the catch observation method. In fact, the dispersed nature of landings and the importance of lagoon fishing from a socioeconomic point of view do not facilitate the task of quantifying fish catches. On the other hand, monitoring roadside sales can be an excellent way of discerning fishing pressure by noting the sizes of the fish sold (Madi Moussa 2010). The assessment of fishery production that resulted from monitoring the municipal tax (Galzin et al. 1989) was an underestimate because it only took into account the percentage of fish that were sold, whereas, according to Vieux (2002), such catches only account for 40% of the overall quantity caught in the lagoon. In the same way, Aubanel (1993) and Vieux's (2002) studies — two observations a decade apart that used the same methodology — gave yields that were once again underestimated. However, the three studies gave similar yield figures, which is normal because the sample concerned fishers who sold their catches on the roadside and did not take into account home consumption. The entire coastline of Moorea is a potential landing

Table 2. Yield estimates per surface area unit by type of survey.

Yield (t km^{-2} year^{-1})	Type of data	Source
24.5	Participatory surveys carried out by schoolchildren on Moorea	Brenier 2007
28.14*	Socioeconomic surveys in the village of Maatea on Moorea	PROCFish 2006
22.9	Direct consumption surveys	Yonger 2002
1.01 to 2.2	Quantities sold on the roadside	Vieux 2002
0.7 to 1.4	Quantities sold on the roadside	Aubanel 1993
1.2 to 1.4	Extrapolation of fishing data	Galzin et al. 1989

* Reef fishery yield for the township of Maatea only.

area for fishers so it is very difficult, if not impossible, to monitor catches that do not go through conventional sales channels. In addition, this technique ignores recreational fishing catches, which are not counted despite their high levels (Brenier 2009).

Consumption surveys and bias

When you look at the average annual, per capita consumption of fish, French Polynesia is considered to be one of the countries with the highest levels of consumption (Kronen et al. 2006). On Moorea, annual consumption is nearly 110 kg per inhabitant (Yonger 2002), whereas the mean annual per capita figures for the Pacific Islands region are between 4.8 kg and 40 kg, with an average of 23 kg (Labrosse et al. 2006). Even if it is difficult to compare the results of consumption surveys carried out under different circumstances and using different methodologies, the gap between the estimates in French Polynesia and the maximum values for other Pacific Islands countries is intriguing and encourages consideration of possible biases of these methodologies and the context of each survey.

In regards to survey methodology, it can be seen that of the four variables used to collect data during a consumption survey — fish family, origin of fish eaten, quantity eaten at each meal, and weekly frequency of meals — only "weekly frequency of meals" appears to be slightly overestimated (Gilbert 2006). This slight overestimate may be due to a poor interpretation of the term "meal". It may be that eating leftovers was reported as a meal, thereby artificially raising the number of meals .

In terms of the context, the "one-off" nature of the surveys was a source of bias for the average annual estimates made. In fact, annual figures were extrapolated from average weekly estimates. This relationship was based on a presumption that eating habits and fishery production remain stable over time (Gilbert 2006). In the same way, quantities eaten were assessed based on the number of fish eaten by species, their sizes or, more rarely (for oceanic species), their weights. Fish sizes were generally estimated with gauges and size and weight conversions used biometric ratios. Size and weight ratios were not always calculated in a precise manner. In fact, when no species ratio existed, the studies used ratios for similar species (Gilbert 2006). So, the information collected from households was more qualitative than quantitative because it was based on perceptions. It called on the short-term memory of the person interviewed and his or her ability to convert an image or a memory into a physical size (Gilbert 2006).

However, indirect studies based on household seafood consumption surveys do offer a good alternative for studying fishery production in these settings. Among other things, they take into account the catches of all types of fishers, including recreational fishers. They have also been subjected to a larger number of studies over the past few years (Kuster et al. 2006; Lagadec 2003; Léopold et al. 2004; Yonger 2002). Léopold et al.

In Moorea, Brenier trained schoolchildren in how to carry out household fish consumption surveys in their homes. Average per capita consumption of lagoon fish calculated from data collected by these schoolchildren was almost the same as that calculated from data collected by scientists in previous household surveys (Image: A. Brenier).

(2004) calculated the prediction error for production based on consumption surveys to be 4.5%. Kuster et al. (2006) showed that catch estimates, fishing effort and fish consumption data (using household surveys) were coherent and did not differ statistically from those resulting from direct surveys. As with participatory surveys, there were no differences between average per capita consumption of lagoon fish calculated from the data collected by schoolchildren or from data collected by scientists (Brenier 2009). Other studies where schoolchildren were involved in the collection of scientific data have shown that they can produce reliable data (Au et al. 2000; Delaney et al. 2008; Nicholson et al. 2002).

Which fishery production estimate is the most reliable?

Based on the obvious signs of overexploitation noted in Moorea's lagoon and the MSY figure of 23 t km^{-2} $year^{-1}$ calculated by Gazin in 1987, it is reasonable to think that Moorea's current reef and lagoon fisheries yield is higher than that figure, and is probably closer to 25 t km^{-2} $year^{-1}$. This would tend to confirm that indirect estimate studies based on consumption and perception surveys are the most relevant for estimating fishery production and yields in Moorea's lagoon.

Conclusion

Fishery activities in Moorea's lagoon are quite difficult to monitor and assess because they vary greatly and are quite dispersed. Several categories of fishers (commercial, subsistence and recreational) use a wide range of fishing techniques for sales, exchange, and home consumption purposes. Over a period of 25 years, several studies have tried to assess fishery production in Moorea's lagoon, with each study using a specific methodology. There is a wide gap in the estimates of fishery production when using catch monitoring methods (0.7–2.2 t km^{-2} $year^{-1}$) and when using consumption or participatory socioeconomic consumer surveys (22.9–24.5 t km^{-2} $year^{-1}$). Taking into account the bias found in each estimating method, it seems that methods involving socioeconomic surveys give the most realistic fishery production estimates. In fact, those methods are better at taking into account catches by all fishers in contrast to catch monitoring methods that only consider catches that are sold but not those from recreational fishing. Finally, signs of overexploitation in this lagoon have lead us to think that current fishery production is probably higher than the MSY of 23 t km^{-2} $year^{-1}$ calculated by Galzin, and this would confirm that Moorea's current reef and lagoon fisheries yield is likely closer to the values estimated by socioeconomic surveys, about 25 t km^{-2} $year^{-1}$.

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