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The eels of French Polynesia: Taxonomy, distribution and biomass*

Gérard MARQUET** and René GALZIN**

Abstract: Electric fishing carried out in the inland waters of the five archipelagos that constitute French Polynesia has corroborated the presence of three species of eels: *Anguilla marmorata*, *A. megastoma* and *A. obscura*. Meanwhile the altitudinal distribution of those three species in the visited island has been established and their biomass assessed.

1. Introduction

French Polynesia (Fig. 1) covers a vast oceanic region located at the eastern limit of the Indo-Pacific province. The land masses of Polynesia spread over an area situated between 134° W and 154° W longitude and 8° S and 28° S latitude.

French Polynesia is made up of 118 islands and islets, high volcanic islands (35) and low coral islands or atolls (83) that represent, together, an emerged area of 4000 km^2 scattered over 2,500,000 km^2 of ocean.

These islands form five archipelagos dispersed along a general north-west, south-east axis:

* The Austral Archipelago (141 km^2) includes 7 islands, one of which is an atoll.

* The Gambier Archipelago (23 km^2) is made up of 9 volcanic islands, surrounded to the north and east by a barrier reef.

* The Marquesas Archipelago (997 km^2) contains 12 islands, one of which is an atoll.

* The Society Archipelago (1618 km^2) is composed of 14 islands: 9 high volcanic islands and 5 atolls.

* The Tuamotu Archipelago (850 km^2) includes 76 atolls.

Apart from the SCHMIDT's (1927) publication on the eels of Tahiti, the other publications deal with ichthyological fauna with few references to freshwater fauna.

The Society Archipelago is the best known so far. Its ichthyological fauna have been described by KENDALL and GOLDSBOROUGH (1911), SCHMIDT (1927), FOWLER (1932), HERRE (1931,1932), POLL (1942), EGE(1939) and RANDALL (1973).

The other archipelagos have been less investigated owing to their isolated situation. However, the Marquesas Archipelago has been studied by FOWLER (1932), PLESSIS and MAUGE (1978) and RANDALL (1985). The Gambier Archipelago has been prospected by SEURAT (1934) and FOURMANOIR *et al.*(1974). The Austral Archipelago has been particularly neglected to the exception of Rapa Island. Tubuai has been visited by PLESSIS (1980). The brackish waters of the Tuamotu atolls are still to be prospected, yet SEURAT (1906) has reported the sighting of eels in Fakarava.

This lack of information about freshwater fauna especially where Anguillidae are concerned is all the more regrettable that it affects a zone of great geographical specificity; indeed, French Polynesia is situated at the eastern limit of presence of the genus *Anguilla* in the Indo-Pacific province.

2. Islands choice criteria

On account of their easy access and the presence of a logistic support provided by the Department of Rural Economy, 11 islands (Fig. 1) have been investigated as part of this study: Rurutu and Tubuai in the Austral Archipelago, Mangareva and Taravai in the Gambier Archipelago, Hiva Oa, Nuku Hiva, Ua Huka and Ua Pou in the Marquesas Archipelago, Moorea and Tahiti in the Society Archipelago and finally Rangiroa in the Tuamotu Archipelago.

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**Ecole Pratique des Hautes Etudes, Laboratoire d'Ichtyoécologie Tropicale et Méditerranéenne, UACNRS 1453, Université de Perpignan, 66860 Perpignan Cedex, France

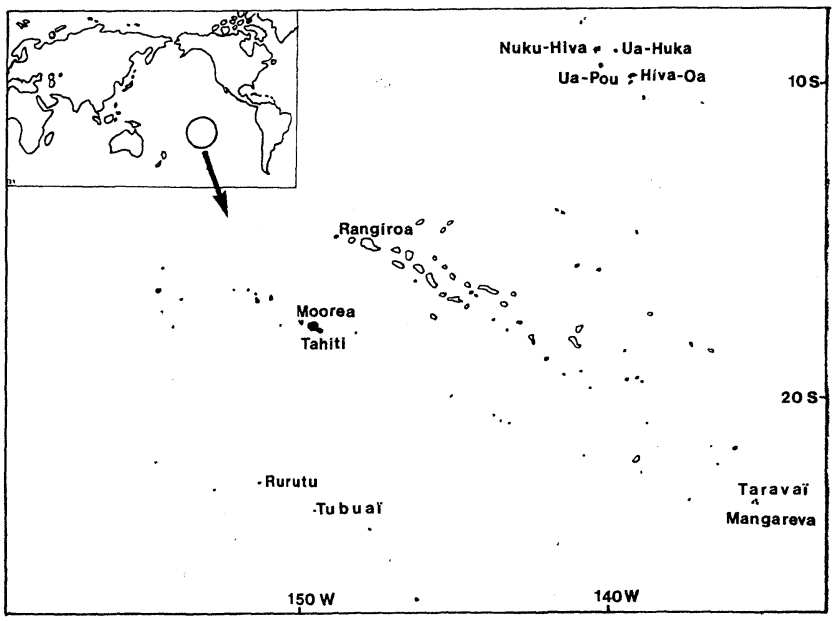

Fig. 1. General map of French Polynesia showing the position of the eleven relevant islands.

3. Materials and methods

Taxonomy

Eels' identification is based on the best defined characters, as specified by SCHMIDT (1927), EGE (1939), MARQUET and LAMARQUE (1986) and MARQUET (1987).

Catching methods

Two methods of capture have been used: electric fishing mainly and rotenone poisoning occasionally. Various generators have been used: the "Cormoran" (GOSSET, 1975), the "Martin-Pêcheur" (GOSSET *et al.*,1971) and an electrogen group "Cadmit Super Champ" (220 V AC, 300 Hz).

The "Cormoran" gives a polarised rectangular impulsions output, at 100 and 400 Hz, with a cyclic ratio adjustable between 10 and 50%. Five tensions are available between 100 and 400V. The power output is 1000 W. This apparatus has been designed for brackish waters within a 500 to 5000 μS cm^{-1} conductivity range.

The "Martin-Pêcheur" is a portable, battery operated apparatus, with a 180 W output, weighing 12 kg, battery included. It gives polarised rectangular impulsions with a choice of two frequencies: 100 or 400 Hz with a cyclic ratio continuously adjustable between 5 and 25%. Three tensions are available: 150, 200 and 300 V. This apparatus has been designed for waters within a 50 and 1000 μS cm^{-1} conductivity range.

Rotenone poisoning was used only where the above generators were not suitable to the conductivity of the investigated waters.

Stock assessment method

The DE LURY method (1947) has been chosen for its quickness and easy use. It consists in performing several consecutive fishing operations without returning the captured eels to the river. The regression of the number of catches allows the definition of a 'constant of efficiency', which is necessary for the computation of the initial stock. In the present study, the fishing efficiencies were always very high, especially for large sized eels which constitute the main part of the biomass. Therefore two consecutive fishing sessions were more than sufficient to obtain reliable results. Moreover, the constancy of

the fishing efficiencies found in this way in the various habitats allows, to a certain extent, the extrapolation of the results obtained from a single fishing session. In effect, two kinds of operations have been performed.

a) Operations involving two consecutive fishing sessions. They have allowed not only the estimation of the stock on each location but also the calculation of the fishing efficiency according to species and size classes.

b) Operations involving a single fishing session. The efficiencies calculated previously have been re-used here. To make up for the efficiency variations from one site to another, the operator was led to introduce a correcting factor based on experience. In that case, the word 'appreciated' stock will be used in opposition to the word 'estimated' stock utilised for results obtained by the more reliable 'two fishing sessions' operations.

The first method has been used in the Society Archipelago but the second method had to be used in the other archipelagos owing to lack of time.

At first a stop net (0.5-cm mesh) was used at both ends of the fishing site to prevent any emigration or immigration during the fishing sessions. As it appeared that this precaution could be dispensed with, stop nets were not used in the later fishing operations.

Prospection of the various types of habitat

In Tahiti island, numerous streams have been investigated (MARQUET, (1988): the Ahonu, the Faatautia, the Fautaua, the Moaroa, the Onohea, the Papeiti, the pk = 14,5 km rivulet, the Punaruu, the Puorooro, the Tiirahi, the Tuauru, the Vaihiria, the Vaipuu, the Vaitaara, the Vaite and the Vaitoare.

On the other hand, stagnant waters have been insufficiently prospected because, as a rule, their high conductivity makes the use of electric fishing impossible. Lake Vaihiria has been visited three times: in May 1982, May 1983 and October 1984.

In Moorea island, much attention has been devoted to the study of the Niuroa and Opunohu rivers.

For the other islands, the prospected streams are given below: Rurutu island: the Puputa, the Tevaavai, the Tevaipa, the Vaioivi, the Vaipapa and the Vaipurua.

Tubuaï island: the Hautara, the Taahuaai, the Tamatoa, the Tehaunatieva, the Vaiohuru, the Vairani and the Matavahi swamp.

Mangareva island: the water catchment rivulet and Gatavake rivulet.

Taravai island: the water catchment rivulet.

Hiva Oa island: the Faakuaa, the Taaoaa, the Vaioa, the Vaipaee and the Vaiutu.

Nuku Hiva island: the Taiohae, the Taipivai, the Tapueaho and the Vaipupui.

Ua Huka island: the Hane, the Vaikivi and the Vaipae.

Ua Pou island: the Anakooma, the Mereka, the Paaumea and the Paeoa.

In the Rangiroa atoll, rotenone poisoning has been employed on the Hoa Vaimate laguna and on the site of the disused fish breeding station of Pavete.

Rivers' zonation

A three zone river partition has been retained to study and explain eels distribution in French polynesian rivers: lower course, middle course and upper course.

The lower course is short, being limited to the littoral area. The estuary area, submitted to marine influence, must be distinguished from the river upstream with low conductivity waters.

The middle and upper courses run down the original volcanic cone. The average slope of the middle course is less than 10%. The upper course has a steeper gradient, inducing strong currents, a scarce aquatic vegetation and a bottom of rocks and boulders. The transition between the middle and upper courses is often materialized by a high waterfall.

Main physical features of Polynesian eels' habitats

Those features have been exhaustively described, for the first time, in a study giving rise to a Doctorate thesis (MARQUET, 1988).

The high islands sometimes have numerous rivers and rivulets. This is the result of heavy rainfalls and of intensive erosion of the volcanic cones constituting these islands.

There were no hydrometric stations in French Polynesia before the creation and development of a network in Tahiti, in the early seventies, by the O.R.S.T.O.M. The measurements made by that office have shown that the main streams have a typically torrential rate of flow.

Apart from running waters, there are stagnant waters chiefly in the usually narrow bands of littoral plains. In Tahiti island, an altitudinal lake can be found: Lake Vaihiria (470m).

The importance of the hydrographic system in the various high islands depends on their altitude and their surface area. The ratio of flowing water to stagnant waters varies from one island to another. Tubuaï in the Austral Archipelago shows an exceptionally important amount of stagnant waters.

Physical and chemical data about the rivers are few and mainly recent. The lack of geological diversity of high islands explains the fairly uniform composition of their waters.

The waters of streams originating in basaltic rocks are weakly mineralised. Their conductivity varies from 40 to 150 μS cm^{-1}. Their pH is comprised between 7 and 8 rather nearer 8 than 7. Oxygenation is very good, especially in high ground waters (9 mg ℓ^{-1} on average). Waters are mainly bicarbonated, and the main cations are calcium, magnesium and sodium. The nitrate content is low, and silicate content varies according to the rivers.

Howevr on low ground, stagnant waters are highly mineralised, owing to saline intrusions. Obviously, in contrast with high islands, atolls can have no hydrographic network but only shallow lagunas and ponds of highly conductive brackish waters.

4. Results

Taxonomy

Among the 16 eel species recorded by EGE (1939), three can be found in the French Polynesian inland waters: *Anguilla marmorata* (QUOY and GAIMARD, 1824), *Anguilla megastoma* (KAUP, 1856) and *Anguilla obscura* (GÜNTHER, 1871).

Geographic distribution

A. marmorata (Table 1) is established everywhere except in the Taravai islet.

A. megastoma does not occur in the Marquesas Archipelago, in the most southern part of French Polynesia and in the Rangiroa atoll.

A. obscura does not inhabit the Marquesas Archipelago and the Taravai islet.

Table 1. Presence (1) or absence (0) of eel species in the eleven studied islands.

	A. marmorata	*A. megastoma*	*A. obscura*
Austral Archipelago			
Rurutu	1	1	1
Tubuaï	1	0	1
Gambier Archipelago			
Mangareva	1	1	1
Taravaï	0	1	0
Marquesas Archipelago			
Hiva Oa	1	0	0
Nuku Hiva	1	0	0
Ua Huka	1	0	0
Ua Pou	1	0	0
Society Archipelago			
Moorea	1	1	1
Tahiti	1	1	1
Tuamotu Archipelago			
Rangiroa	1	0	1

Altitudinal distribution

In the Society Archipelago (SCHMIDT, 1927; MARQUET and LAMARQUE 1986), *A. marmorata* and *A. megastoma* occur in running waters. The dominant species are *A. marmorata* below the waterfalls and *A. megastoma* above. *A. megastoma* is established in the Vaihiria lake. *A. obscura* is restricted to estuaries and shallow stagnant waters.

The altitudinal distribution in other archipelagos is mainly the same (Table 2). However, in some archipelagos one species becomes ubiquitous. Such is the case for *A. obscura* in the Austral Archipelago and for *A. marmorata* in the Society Archipelago.

A. marmorata cannot be found in the upper course when the waterfall that separates it from the middle course is too high. Such high waterfalls occur in the Marquesas islands.

Biomass

The various species of eels are not distributed uniformly throughout French Polynesia (Table 3).

In the Austral Archipelago, *A. obscura* colonizes both running and stagnant waters. Therefore, its biomass is relatively high (from 142 to 92 kg ha^{-1}). In running waters, where *A. megastoma* is present, its biomass is high (291 kg ha^{-1} in Rurutu). *A. marmorata* is moderately abundant (80 kg ha^{-1} on average).

In the Gambier Archipelago, the three species are present. In running waters, the con-

Table 2. Distribution of the three eel species in the studied islands.

	Running waters				Stagnant waters		
	High islands				High islands		Atoll
	Lower course		Middle course	Upper course	Littoral area	Lac Vaihiria	
	Estuary	Upstream					
Anguilla marmorata							
Rurutu		+	+	+	+		
Tubuai		+	+				
Mangareva		+					
Hiva Oa	+	+	+	+			
Nuku Hiva,	+	+	+	+			
Ua Huka	+	+	+	+			
Ua Pou	+	+	+	+			
Tahiti	+	+	+	+	+		
Moorea	+	+	+	+	+		
Rangiroa							+
A. megastoma							
Rurutu			+	+			
Mangareva			+	+			
Taravai			+				
Tahiti			+	+		+	
Moorea			+	+			
A. obscura							
Rurutu	+	+	+	+	+		
Tubuai	+	+	+	+	+		
Mangareva	+				+		
Moorea	+				+		
Tahiti	+				+		
Rangiroa							+

Table 3. 'Appreciated' biomasses (kg ha^{-1}) for the three eel species in the five archipelagos.

	Austral		Gambier		Marquesas				Society	Tuamotu
	Rurutu	Tubuai	Mangareva	Taravai	Hiva Oa	Nuku Hiva	Ua Huka	Ua Pou	Moorea and Tahiti together	Rangiroa
A. marmorata	96	65	54	0	221	94	226	291	261	+
A. megastoma	291	0	559	267	0	0	0	0	264	0
A. obscura	98	142	129	0	0	0	0	0	13.5	+

Table 4. Estimated biomass (kg ha^{-1}) of the three eel species in Tahiti-Moorea rivers.

	Lower course		Middle course	Upper course
	Estuary	Upper waters		
Number of investigated rivers	4	6	6	4
A. marmorata	191	424	139	60
A. megastoma	0	0	2	397
A. obscura	7	0	0	0

cept of biomass, as expressed in kg ha^{-1}, is not very significant because of the scarcity and narrowness of the rivulets that make up the hydrographic system. The dominant species is *A. megastoma* with a high biomass (559 kg ha^{-1} in Mangareva). *A. marmorata* is much rarer (54 kg ha^{-1}). In stagnant waters, *A. obscura* is well established with a biomass of 129 kg ha^{-1} in Mangareva.

In the Marquesas islands, the only species that can be found is *A. marmorata*. Its average biomass over the four studied islands is 208 kg ha^{-1}.

In the Society islands, the three species are present. *A. marmorata* and *A. megastoma* are predominant with a biomass of 261 and 264 kg ha^{-1} respectively. *A. obscura* has shown a much lower biomass (13.5 kg ha^{-1}).

In the Rangiroa atoll, the generators available were not suited to the conductivity of the water. Therefore, it was not possible to appreciate the biomass of the two species that were found, namely *A. marmorata* and *A. obscura*.

Owing to the greater number of data concerning the Society Archipelago, it has been possible to 'estimate' the biomass of the three species in the Tahiti-Moorea rivers (Table 4).

In the lower course and the middle course, *A. marmorata* is by far predominant with a biomass varying from 139 kg ha^{-1} to 424 kg ha^{-1}. In the upper course, its biomass drops to 60 kg ha^{-1}.

A. megastoma, scarcely present in the lower and middle courses, becomes predominant in the upper course with a biomass of 397 kg ha^{-1}.

A. obscura is restricted to estuaries with a low biomass (7 kg ha^{-1}).

5. Discussion and conclusion

Taxonomy

The presence of three eel species in French Polynesia is consistent with SCHMIDT's results (1927), taken up by EGE (1939) for the Society Archipelago only.

However, EGE (1939) mentions that specimen of a fourth species, captured in Tahiti and labeled *A. australis*, belongs indeed to the subspecies *A. australis schmidti*. No such eel has been found among the few thousands that were caught in the course of this study. In

fact the known distribution of that species, limited to New Zealand and New Caledonia, suggests that French Polynesia is situated too far from its usual habitat. Nevertheless, it may be that the eel mentioned by EGE (1939) became lost by accident, just like *A. anguilla* bas been reported by EGE (1939) in Kenya and *A. obscura* in South Africa by JUBB (1957). However,it remains possible that the eel seen by EGE (1939) in the Hamburg Museum had been wrongly labelled as coming from Tahiti.

Geographic distribution

A. marmorata

In French Polynesia: The presence of this species has long been known in Tahiti as well as in the Marquesas islands (EGE, 1939; FOWLER, 1932; HERRE, 1936). The present survey has extended the known distribution area of *A. marmorata* towards the east as far as Mangareva (135°W). *A. marmorata* may now be considered as ubiquitous in French Polynesia. Its absence from the Taravai islet can be explained by the lack of any significant river. In any case, the Taravaï islet can be considered as part of the nearby Mangareva where *A. marmorata* is present.

In the Indo-Pacific province: This ubiquity in French Polynesia is in agreement with the wide Indo-Pacifique distribution of *A. marmorata*. In the Indian Ocean: It has been recorded in South Africa by JUBB (1964), in Madagascar by KIENER (1965) and in the Reunion island also by KIENER (1981). In the Pacific Ocean, it can be found from the Philippines (EGE, 1939) to Japan (NISHI and IMAI, 1969) and from New Guinea to Polynesia (EGE, 1939).

A. megastoma

In French Polynesia: This species has been observed (EGE, 1939) in the Society Archipelago (Tahiti, Moorea and Raiatea) and in the Gambier Archipelago (Mangareva). The present work has shown that *A. megastoma* does not occur in the Marquesas Archipelago and in the Tubuaï island. This means that the distribution of this species is restricted to a narrow range of latitude.

In the Indo-Pacific province: This distribution in French Polynesia can be paralleled with the general distribution of *A. megastoma* in the Indo-Pacifique province. Indeed, *A. megastoma* is known from the Solomon islands to Pitcairn island (EGE, 1939).

A. obscura

In French Polynesia: The presence of this species has been recorded (EGE, 1939) in Tahiti island and in the Austral Archipelago (Tubuaï and Rapa). The present work shows that *A. obscura* is absent from the Marquesas Archipelago. The distribution of this species is roughly that of *A. marmorata*, minus the Marquesas islands.

In the Indo-Pacific province: This distribution in French Polynesia again can be paralleled with a relatively wide distribution of *A. obscura* in the Indo-Pacifique area. Indeed, *A. obscura* is known in Australia (BEUMER *et al.*, 1981) and from New Guinea to Polynesia (EGE, 1939).

The present paper advances the knowledge of the Polynesian eel distribution in an area of scientifing interest. Indeed, it is situated at the eastern limit of presence of the genus *Anguilla* in the Indo-Pacific province (Fig.2).

In that area, the number of eel species decreases sharply to the north. In the Marquesas islands (9°S), a single species (*A. marmorata*) has been captured, and in Hawaï (24° N) no eel has ever been reported (SCHMIDT, 1925).

Conversely, to the south, three species have been captured in Rurutu (22° S), two in Tubuaï island (23°S) and the same number (PLESSIS, 1987) in the Rapa island (27°S). Rurutu and Tubuaï are two neighboring island, however the former has a more precipitous character. This difference could explain the absence of *A. megastoma* in Tubuaï. On the other hand, Rapa similar to Rurutu in its relief shows no trace of *A. megastoma*. Since the absence of this species cannot be attributed to the morphology of the island, it is likely to be related to its more southerly latitude.

At the extreme east of French Polynesia, three species can be found in Mangareva

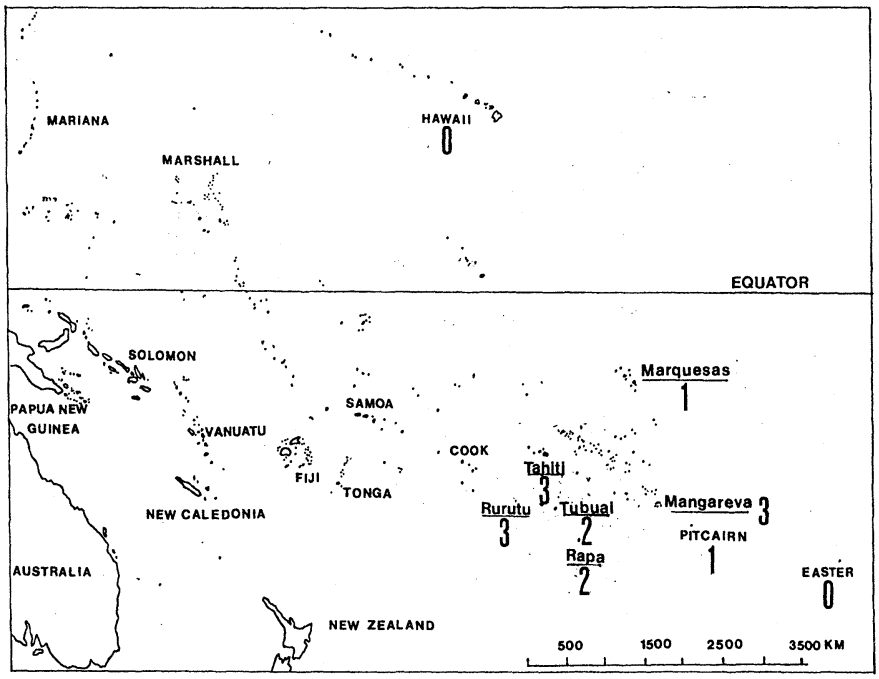

Fig. 2. Number of eel species in the East Pacific Ocean.

(135° W), a single species (EGE, 1939), *A. megastoma*, in the Pitcairn island (130°W) and none (SCHMIDT, 1925) in Easter island (109°W). The precipitous character of the Pitcairn shoreline could explain the absence of *A. marmorata* and *A. obscura* from this island. The absence of any species of eels in the Easter island must be attributed to its state of isolation.

Altitudinal distribution

The present research has shown, for the first time, the presence of *A. marmorata* and *A. obscura* in a Polynesian atoll. This result was foreseeable because eels are euryhaline.

A. marmorata: As a rule, in high islands, it can be found in stagnant waters, as well as in running waters. In the latter case, it is present all the way from estuary to upper course. This adaptability is specific of that species. In Madagascar, it settles within 500m from the sea (KIENER, 1965). In South Africa, it occurs in coastal areas (JUBB, 1964). However, it has been seen in Rhodesia as far as 1000 km from the estuary (FROST, 1957) and in the Philippines at more than 1530 m above the sea (SCHMIDT, 1927).

A. megastoma: In high islands, it inhabits the upper course of streams. No reference has been found about the distribution of *A. megastoma* in territories other than French Polynesia.

A. obscura: In high islands, it is usually restricted to lower freshwater reaches and to estuaries. This distribution seems to characterize short finned eels; for instance *A. bicolor bicolor* in Madagascar (KIENER, 1965) and *A. australis schmidti* in New Zealand (BURNET, 1968).

Biomass

A. marmorata: The biomass is very high in the Society Archipelago, and to a lesser degree in the Marquesas islands though *A. marmorata* has no other species to compete with in that archipelago. In the east, the biomass drops considerably, and to the south it decreases gradually. Out of the three species, *A. marmorata* spreads the most to the north; on the other hand, its extension eastwards and southwards is limited.

A. megastoma: Wherever it exists, its bio-

mass is always high. This result is in conformity with the fact that where ecological conditions are difficult, the surviving species meet few competitors.

A. obscura: The biomass of this species is certainely undervalued because it lives in strongly conductive waters. Therefore, electring fishing was too often impossible with the available generators. Out of the three species, *A. obscura* seems to reach furthest to he south.

The 'appreciated' or 'estimated' biomasses are generally high. By way of comparison, BURNET (1952) gives average values in the range of 100 kg ha^{-1} for *A. dieffenbachi* in New Zealand rivers. TESCH (1977) finds variation from 3 to 50 kg ha^{-1} for *A. anguilla* in German rivers. SLOANE (1984) gives a range of 0.4 kg ha^{-1} to 230 kg ha^{-1} for the biomass of *A. a. australis* in Tasmanian rivers.

Several reasons explain the high values obtained in Polynesian rivers:

– The rate of growth seems higher for species living in tropical conditions than for those in temperate countries.

– The practice of eel fishing is little spread in French Polynesia and elvers are not fished at all.

– There is little or no competition from other fish, especially for bigger specimens.

The importance of the existing stock of Polynesian eels is such that the possibility of drawing a moderate amount of elvers or young eels with fish farming in view could be envisaged without the risk of affecting the overall population. The atolls would furnish a suitable site for aquaculture.

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フランス領ポリネシアのウナギ類：その分類，分布および現存量

Gérard MARQUET and René GALZIN

要旨：フランス領ポリネシアを構成する５つの群島の内水面で，電気漁法による調査を行った結果，３種のウナギ類；*Anguilla marmorata*, *A. megastoma* および *A. obscura* の存在が確認された。調査した島における，これら３種のウナギ類の高度分布を調査するとともに，その現存量を評価した。