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Workshop on South Pacific freshwater eels, Suva, Fiji, 13–15 June 2016: Current knowledge and future research

T.D. Pickering and P. Sasal

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Cover:
Photo: A giant marbled eel *Anguilla marmorata* on sale in Suva Market, Fiji Islands. Y. Aoki
Illustration: Depiction of a scene from the famous Polynesian legend, 'Hina and the Tuna', about the origin of coconuts. Boris Colas, SPC.

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Abbreviations and acronyms

CNRS	Centre National de la Recherche Scientifique
CRIOBE	Centre de Recherche Insulaire et Observatoire de l'Environnement
GRG	Grace Road Group
IRCP	Institut des Recifs Coralliens du Pacifique
IUCN	International Union for Conservation of Nature
MAF	Ministry of Agriculture and Fisheries (Government of Samoa)
MoFF	Ministry of Fisheries and Forests (Government of Fiji)
PICTs	Pacific Island countries and territories
SPC	Pacific Community
USP	The University of the South Pacific

Executive summary

A scientific workshop on South Pacific freshwater eels (*Anguilla* spp.) took place in Suva, Fiji Islands, from 13 to 15 June 2016. The workshop was jointly organised by the Centre de Recherche Insulaire et Observatoire de l'Environnement, the Pacific Community, and the University of the South Pacific. Participants included a cross-section of representatives from national fisheries administrations, private sector investors, scientists from regional and international research and tertiary education institutions, non-governmental organisations working in biodiversity conservation, and fish farmers.

The purpose of the workshop was to update stakeholders on the current state of knowledge about South Pacific freshwater eels, and to determine the priorities in scientific research needed to underpin and support conservation and sustainable utilisation of tropical freshwater eels in Pacific Island countries and territories.

Speakers at the workshop related experiences to show that tropical freshwater eels in the South Pacific are iconic and high-status, able to grow to a very large size, and famous for their good flavour. International researchers described the long migrations undertaken by eels from rivers to (as yet) unknown mid-ocean locations for breeding. Eels are important figures in Pacific indigenous cultures and mythologies. They play a significant part in subsistence fisheries although they are not yet highly commercialised in either commercial fishing or aquaculture.

Pacific fisheries administrations report an increasing level of enquiries about freshwater eels from foreign investors and commodity traders, mainly from Asia and particularly from China. Local politicians are now becoming interested in eels. This trend appears driven by high levels of commercialisation and serious depletion of eel resources in other regions of the world where eels are now listed as 'endangered'. Threats to eels include not only fishing but also water pollution, river habitat degradation, and barriers to eel migration.

Eel conservation and sustainable utilisation are not yet critical issues for Pacific Island countries and territories, but are becoming emerging issues. South Pacific eels are currently listed as 'data deficient' in the International Union for Conservation of Nature (IUCN) Red List, and to date, there has been almost no systematic scientific study of tropical South Pacific eels. Large knowledge gaps exist about both the science of eels (e.g. their breeding, migration patterns, recruitment, growth, abundance, and age of reproductive maturity) and the cultural status of eels (e.g. particular values to be defended through eel conservation). Such knowledge is needed to underpin policies and management plans for eel conservation and sustainable utilisation. When there are large knowledge gaps, a precautionary approach should be adopted regarding commercial-scale fishing for glass eels or adult eels, and degradation or development of eel habitat.

In the workshop practical sessions, typical freshwater eel research techniques were demonstrated so that participants could gain an idea of the methods and logistics involved. These techniques included setting fine-mesh nets for glass eel capture, glass eel data collection and otolith extraction, electro-fishing for adult eels, and pit-tagging of adult eels for population studies.

Priorities were set for the research needed to fill knowledge gaps about South Pacific freshwater eels. These include: i) adoption by fisheries administrations of routine periodic sampling to show trends through time in eel recruitment and adult population abundance; ii) selection by tertiary institution staff and post-graduate students of detailed eel biology topics such as eel genetics or the age and season for eel breeding migrations; iii) market research to establish the true demand and likely value in Asian markets of the particular eel species present in the South Pacific; iv) documentation of cultural and subsistence values associated with eels; and v) formulation of science-based policies and management plans to conserve and sustainably utilize freshwater eels.

Workshop participants observe electrofishing research techniques for adult eels. (Photo: K. Tsukamoto)

Opening session

1. The meeting was opened by co-organiser Ciro Rico, Professor of Marine Studies at the University of the South Pacific (USP), who welcomed all participants.

2. Tim Pickering, Inland Aquaculture Advisor with the Pacific Community (SPC), introduced participants to the global context for work on the conservation and utilisation of freshwater eels (Anguillidae). Eel resources are valuable; for example, for the aquaculture of eels in Japan the farm gate price is JPY 3000 per kg (USD 30, or FJD 60), which retails in *unagi kabayaki* (grilled eel) restaurants for JPY 15,000 per kg (USD 150, or FJD 300). Freshwater eels have been well researched in other regions, but also threatened to the point where they are now highly endangered. By comparison, the South Pacific region is a 'last frontier' for freshwater eels, and the utilisation of this iconic riverine fish is still largely at the subsistence level although commercial pressures will be inevitable now that eels are scarce in other regions of the world. This means the freshwater eels of the South Pacific are in danger of becoming the next 'sea cucumber', which, due to its high value, is vulnerable to depletion. There has not yet been any systematic research of South Pacific freshwater eels, of the type needed to underpin policies and planning in anticipation of increased levels of eel utilisation, or increased threats such as habitat degradation or barriers to migration.

a A giant marbled eel *Anguilla marmorata* on sale at a Suva market. (Photo: Y. Aoki)

b An eel cultural artefact: this Fijian war club is on display in the Fiji Museum in Suva (Photo: T. Pickering)

c Workshop participants examine the features of a fine-mesh net of the type that can be set in river mouths to catch glass eels. (Photo: T. Pickering)

3. Pierre Sasal of Centre National de la Recherche Scientifique (CNRS) in French Polynesia spoke of the need for fundamental research on South Pacific eels at several levels, due to their long migrations from the deep ocean to mountain tops. South Pacific eels spawn in the deep sea at undiscovered locations, swim long distances as leptocephalus larvae for many days to reach islands where they become glass eels, and become recruited to adult populations of juvenile 'yellow eels' in rivers. Then, when they reach an unknown age and size, some eels will change to 'silver eels' for another long migration back to their ancestral spawning grounds in the deep ocean.

4. For conservation, these spawning grounds and migration routes need protection. For fisheries management, it is necessary to have estimates of population parameters such as spawning fecundity, recruitment levels, growth rates, and age of first maturity in order to successfully apply fish stock assessment techniques. But for South Pacific eels, there is no such information.

5. A 'South Pacific Eels Group' has been formed across several institutions in order to begin addressing these knowledge gaps via the coordination of research activities.

6. The purpose of this workshop, the second one to be held in three years, is to: update stakeholders about the current state of knowledge of South Pacific FW eels, and form a consensus about the requirements in fundamental and applied research needed in the various Pacific Island countries and territories (PICTs) to sustainably manage eel populations.

The life cycle of eels

7. Pierre Sasal of CNRS CRIOBE, gave a presentation on the 'Life cycle of eels'. For freshwater eels, biologists know there must be a bridge between the sea and freshwater. But there is a common misconception that eels breed and spend all their lives in freshwater. Eels are important in Polynesian myth and legend, for example in the story told about Hina (Sina) and the coconut tree. It is now confirmed from research (led by Dr Sasal last year) that eels are no longer present in Lake Vaihiria, the place where Tahitians say the legend of Hina took place, because their migration route is blocked by a hydro dam. It has been known since the 1930s that the American eel (*Anguilla rostrata*) and European eel (*Anguilla anguilla*) both breed in the Sargasso Sea area of the Atlantic Ocean. Then, in the 1990s, it was discovered that the Japanese eel (*Anguilla japonica*) breeds near the edge of the Marianas Trench in a small area of seabed not far from Guam.

8. It is still unknown as to where South Pacific eels breed. Their spawning grounds could be anywhere within quite a large area of ocean, in the vicinity of Fiji or Vanuatu. Based on a study of the genetic relationships within adult *A. marmorata* eels from the South Pacific[1], this species could have as many as four spawning grounds. There are three ways to estimate the approximate location of the spawning grounds of South Pacific eels: conduct plankton tows for leptocephalus larvae, looking for the young newly-hatched stages; find out the age of glass eels when they make landfall, and use ocean current modelling to back-track along the migration path and estimate their hatching location; and release mature silver eels with satellite pop-up tags, to find out where they swim to after they leave land.

[1] Minegishi Y., Aoyama J. and Tsukamoto K. 2008. Multiple population structure of the giant mottled eel Anguilla marmorata. Molecular Ecology 17:3109–3122.

9. The age of glass eels is revealed by daily growth rings in the otolith bones of their inner ear. Knowing the age of each glass eel shows how long it took to reach the capture site from their spawning site. Using ocean current modelling, the approximate location of the spawning site by back calculation from this elapsed swimming time can be estimated.

10. Commercial utilisation of eels is based entirely on wild-caught eels, either of glass eels (for aquaculture) or of adult eels (for capture fisheries). Spawning in captivity and hatchery rearing of *A. japonica* eels has become technically possible after intensive research, although each glass eel costs USD 100 to produce. This price needs to be reduced to about USD 1 or 2 each in order for hatchery production of *A. japonica* eels to be commercially viable. Meanwhile, the eel aquaculture industry in Japan will continue to depend on wild capture of glass eels to stock their farms. Live glass eels in Japan trade at JPY 300,000–500,000 (USD 2,800–4,700) per kg. As a result of the high price they command, there was a recent case of glass eels being smuggled from Europe to Japan in plastic bags inside suitcases by airline passengers who were paid EUR 300 each to be eel 'mules'!

11. Electrofishing is a method of catching adult eels in rivers for biological analysis. The information gained from this can include the identification of eel species from teeth patterns and colour; the eel's length and weight; otoliths (for age determination); gut contents; DNA analysis. Tagging with electronic pit tags and releasing each eel for future recapture allows an estimation of population abundance and individual growth rates (this technique is known as a 'mark-recapture' study). Eel species are categorised as being either shortfin or longfin, according to the ratio of dorsal and anal fins to their total body length.

12. It is important to study silver eels to determine age at first maturity for reproduction, and to be able to protect eels that are about to migrate for reproduction. This is difficult, however, because silver eels are not common and because they must be captured, tagged and released at the right moment when they are beginning their migration. Because they swim to their mid-ocean spawning ground, silver eels undergo daily vertical migrations from near the sea surface at night to depths of 800 m during the day, in order to remain hidden from sharks.

13. In 2007, the global harvest of eels from fisheries was 230,000 t, of which 70% was consumed in Japan. Eels caught from Madagascar sell for EUR 100 (USD 110) per kg in Europe. All of the Northern Hemisphere eel fisheries are now at less than 5% of their populations 30 years ago. *Anguilla anguilla, A. japonica* and *A. rostrata* are listed by the IUCN as 'endangered'.[2,3,4] Because of the IUCN classification, the market has drastically been reduced and consumption of eels in Japan has also declined. China is now the world's largest consumer. Threats to eels include: overfishing, parasites (in the air bladder, which hinders silver eel vertical migrations), pollution, habitat degradation (e.g. gravel extraction, dams, obstacles to migration) and climate change.

14. Workshop participants asked Mr Sasal whether there was a risk of getting ciguatera from eating eels, and Mr Sasal responded that there was not. Another question was asked about how to aquaculture South Pacific eels. Mr Sasal explained that data are needed on the abundance and season of glass eel recruitment. Then the decision needs to be made regarding whether the eels should be grown to market size at the farm, or exported as glass eels for grow-out by eel farms in Asia.

[2] European eel *Anguilla anguilla.* IUCN Red List of Threatened Species assessment, http://www.iucnredlist.org/details/60344/0
[3] American eel *Anguilla rostrata.* IUCN Red List of Threatened Species assessment, http://www.iucnredlist.org/details/191108/0
[4] Japanese eel *Anguilla japonica.* IUCN Red List of Threatened Species assessment, http://www.iucnredlist.org/details/166184/0

Cultural and subsistence aspects of eels for Fiji's indigenous people

15. The next workshop presentation — given by Lekima Copeland with the Institute of Applied Science at the University of the South Pacific — was an 'Overview of the cultural and subsistence aspects of eels for Fiji's indigenous people'. From the current checklist of freshwater fishes in Fiji, there are four species of anguillid eel: i) giant marbled eel, *A. marmorata;* ii) Pacific shortfin eel, *A. obscura*; iii) Polynesian longfin eel, *A. megastoma;* and Indonesian/Indian shortfin eel, *A. bicolour*. Because the morphological evidence can be unclear, the presence of *A. bicolor* in Fiji needs to be confirmed by genetic tools. No work on eel parasites has been done in Fiji.

16. Cultural values for eels are contained within the concept of *vanua*, where the land and its resources are regarded by iTaukei (indigenous Fijians) as a 'three-legged stool', with physical, social and cultural dimensions. In iTaukei taxonomy, *duna* is the generic word for all freshwater eels. The recognised types (corresponding to species) are *diria*, *tautaubale*, and either *badamu* or *malavo*, for *A. marmortata*, *A. megastoma*, and *A. obscura*, respectively. *Anguilla megastoma* is reputed to be able to crawl on land, hence the name *tautaubale*. Mr Copeland reported that whenever he conducts freshwater fish surveys by electrofishing, 9 out of every 10 of the eels caught are *A. marmorata*. He mentioned that he has scarcely ever seen *A. megastoma*.

17. Nakauvadra in Ra Province is the mythological resting place of the gods. It is a tributary of the Rewa, a river that drains one-third of all Viti Levu Island. Spearfishing is done in the dry season in Ra when water levels drop and deep pools become accessible. Eels are a totem for some inland communities. In Naitavuni, Delailasekau and Nasevou villages, visitors are punished by drinking extra kava if they come from a place that eats their totem! There are eel carvings and artifacts in the Fiji museum. Sepeti Matararaba and Elia Nakoro at the Fiji Museum are contacts for information about eel culture and artifacts. Noco is the dwelling place of an eel god. *Duna leka* in mythology is an eel without a tail. If one is seen then it is a good omen for fishing because it is a spirit that helps people to catch fish. People in Naitasiri say that the power to do firewalking is linked to eels, and that it came from Beqa Island. In general, it is difficult for people to share information about the mythology of eels because it is a sacred subject that is very personal to them.

18. Sovi Basin is a protected forest sponsored by the Fiji Water Foundation, and is a 'hot spot' for eels, flagtail fish (*Kuhlia* spp.) and other indigenous fish. Tilapia have reached the area too, and are big, but do not seem to be negatively impacting on native fish. In 2003, tilapia were only in the lower reaches. Now they are above the river gorge.

19. 'River Monsters' Season 7 Episode 5 broadcast by the Animal Planet programme of Discovery Channel is on 'South Pacific Terrors', which is about eels in Fiji. The show's host hunted for one particular eel that was alleged to be aggressive and people wanted to be rid of it. But this claim could simply be a case of Hollywood. In the programme, the eel that was caught was misnamed *tautauvata,* when it was in fact *diria*.

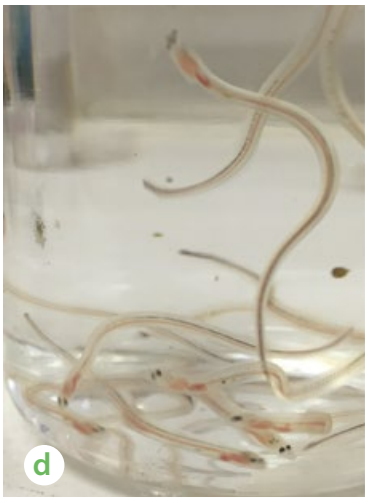
20. Emalu in Navosa is a pilot site of the Ministry of Fisheries and Forests (MoFF), which contains the headwaters of both the Sigatoka River and the Navua River. Mr Copeland

d Glass eels captured from a Fijian river mouth. (Photo: C. Hewavitharane)

e Ulusapeti Tiitii of Samoa Fisheries practices the technique of tagging an eel with an electronic pit tag. (Photo: T. Pickering)

f A very large *A. marmorata* eel captured in the highlands of Viti Levu in Fiji.

g A young leptocephalus larva of *A. marmorata*, captured in the western Pacific by IKMT net. (Photo: M Kuroki)



was once shown many eels that were caught there in a single day, allegedly by spear but the large number caught and the lack of wounds implies that the root of the *Derris* plant was used. Locations for eel fishing are often inaccessible and involve long treks on slippery trails. Waterfalls are called *sukasuka ni ika droka*, meaning places where flagtail fish cannot penetrate farther upstream.

21. At the Suva market several weeks ago, a big eel was put on sale and sold within 10 minutes for FJD 50. Other big eels sold at the Suva market have fetched FJD 80 each. It is not common for freshwater eels to be sold in municipal markets.

22. Eels in Fiji are revered in mythology but information about this is not readily divulged. Eels are greatly appreciated by iTaukei for their good eating qualities. Potential topics on the role of eels in Fijian culture include determining how many communities in Fiji have an eel as a totem, and documenting stories and traditional knowledge about eels.

23. Workshop participants asked the presenter if an eel is a totem, does this mean one's ancestor is an eel? Mr Copeland said, 'No. A totem is like a god who can bring blessings if people look after it.' He also explained that Fijian culture is mostly Polynesian, so they have a similar version of the 'Sina/Hina and the Tuna' story.

24. This presentation opened another door on the life of eels in Fiji, showing that there is still much research to be done in Fiji.

25. Another question asked of the presenter was, 'Could eel aquaculture be a problem in Fiji for cultural reasons?' Mr Copeland replied, 'No, not if proper protocols are followed. If it has potential, then it is a resource that can be developed.'

26. It was also asked whether there is a separate Fijian name for silver eels, and apparently this is unknown.

27. One final comment made was that in Cakaudrove Province, the season for silver eels is March and April. Usually the time of glass eels arriving is also a time of silver eels migrating out to sea. It is the same in Japan.

Private sector perspective on eels in Fiji

28. A private sector perspective about eels in Fiji was given by Ah Rum Song of the Grace Road Group in Navua, Fiji. The Grace Road Group is a church-based business in Fiji that is interested in sustainable food production. Rice is currently their main activity. They take a whole-of-value-chain approach to farming, which includes retail (restaurants) and exports.

29. The Grace Road Group asked themselves what should be the next food area they focus on. The group is originally from Korea, where (like Japan) people are enamoured with eels. Nowadays, eels are scarce in Korea, and most people cannot afford them.

30. European glass eels are no longer available to Korean eel farmers due to a European Union export ban. Instead, they get glass eels mainly from Southeast Asia, such as Indonesia and the Philippines. There are 200 eel farms in Korea, but most of them are half empty because of the global shortage of glass eels. Farming relies on capture-based culture

because breeding eels in captivity is not commercially feasible. Korea also imports adult eels from Australian and New Zealand capture-based fisheries. The supply of glass eels is decreasing and is always fluctuating. There is strong financial incentive to obtain glass eels by whatever means possible.

31. Fijian glass eels are, therefore, highly marketable in Korea. However, the prices paid for glass eels is based on their source and reputation. Fijian glass eels are still an unknown quantity in Korea, in terms of the species mix to be found within catches, and of the characteristics of those species for aquaculture grow-out. This is a marketing challenge for Fiji. Commercial growers in Korea will first want to try some, and will need to grow them out for three or four months before their suitability for aquaculture or marketing becomes apparent.

32. In addition to glass eels, Fiji can also export adult 'yellow eels', whether farmed within Fiji or caught from the wild fishery. Many shops in Korea sell live eels where customers choose their eel based on its appearance. People know about the different types.

33. As a company, Grace Road Group is interested in aquaculture and the processing of eels in Fiji, but before they can begin, there are some important commercial questions that need to be answered. Where can they catch glass eels? What is the season? How many can they catch? What species are in the catch? How can they farm eels in a sustainable way? What is the best way forward from here, to establish commercial aquaculture based on Fijian eel species?

34. Chinthaka Hewavitarane's PhD work in Fiji is the way forward for glass eels. It appears that there are many eels arriving in Fijian rivers. Does the Grace Road Group want to export glass eels for grow-out in Korea, or does it prefer to farm them to market size here in Fiji? What would be the price per kilo for Fiji glass eels?

35. The price of glass eels in Korea varies quite a bit. The Grace Road Group would need to send some to a Korean farmer for grow-out, and then report back with an offer on price. The farmer will want to see for himself, how sturdy Fijian eels are in culture. There is considerable complexity in grow-out, so Grace Road Group is reluctant to take the risk of farming them here in Fiji, at least at first. At present, *A. marmorata* is fairly foreign to Korean and Japanese markets so it is hard to talk about price at this point. This will be determined in due course. It also depends on quantity, to find out if it is worth the investment. *A. obscura* would be popular because of its smooth (not blotchy) skin. Obviously the longer the eels are held and grown in Fiji before export, the greater the economic benefits that will be retained here.

36. Comment from Prof. Tsukamoto: In Japan, the only experience farmers have of Southern Hemisphere eels is those from Madagascar, and these are not welcomed. The Japanese criteria for eel quality is not so much based on appearance of the whole live animal, but rather on texture of the cooked eel fillet. It must not be too oily, but must not be too dry either. It is a delicate balance. South Pacific tropical eels are completely unknown to Japanese eel farmers.

37. In Korea, customers like to choose the eel alive, so live appearance is important and everyone has an opinion about it, which may or may not be related to eating qualities. There is variation in the market requirements for eels in Asia. The Grace Road Group will need to find out how well Fijian eels fit in to these markets.

38. Another issue to consider is that Japanese farmers have invested in a specialised eel farming technique (high temperature), and are not interested in farming any eel species for which they would have to modify their farm infrastructure. This is another issue to face.

39. A participant asked whether the Grace Road Group staff had tried eating eels in Fiji? The answer was yes, with the remark that the taste is different from Korean eels. Korean eels are more oily, and softer in texture. Koreans like freshwater eels more because they are softer and tastier. Fijian eels score about 8 out of 10 (if Korean eels are 10 out of 10).

40. A comment that was made was that there is a need to find an ecofriendly way to improve the taste and flavour of eels, and aquaculture is a way to modify taste (through feed choices).

The status of freshwater eel resources in Fiji

41. Shalendra Singh, Principal Fisheries Officer Aquaculture with MoFF in Fiji, gave a presentation on the 'Status of freshwater eel resources in Fiji: Insights from MoFF on resource inventories, market data, and enquiries received about exploitation'. Mr Singh noted that although eels are not the subject of any periodic and specifically targeted fisheries survey work in Fiji, they are a component of general fishery surveys and resource inventories conducted by MoFF. The most recent such survey was of the fisheries resources of the Sigatoka River, completed in 2015. There was one single, and fairly comprehensive, survey that specifically targeted Fiji's eel resources, and it was conducted in the 1980s by MoFF in collaboration with a visiting Australian scientist.[5]

42. In MoFF fish market survey data, few eels appear on sale, and little market data are available. It appears that eels are mostly consumed for subsistence. No formal eel aquaculture is occurring in Fiji although eels are found as incidental catch when harvesting ponds of other freshwater species such as prawns or tilapia.

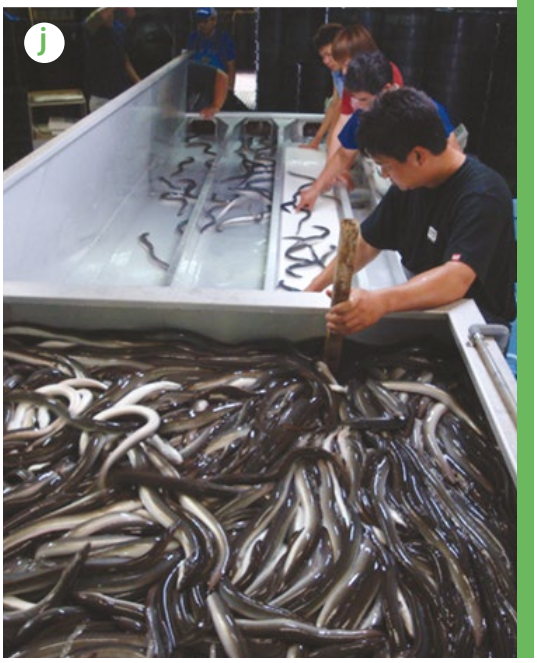
43. MoFF regularly receives queries from potential overseas fisheries or aquaculture investors about the status of eel resources in Fiji, and about any regulations governing glass eel catches or adult eel exports. There is little information available to answer such queries, or to use as a basis for formulating policies or management plans.

44. MoFF sees a need for research to support the conservation and management of eels, and to establish the feasibility and sustainability limits of glass eel capture for aquaculture. For example, what are the numbers of eels recruited annually? The feasibility and sustainability of glass eel capture needs to be demonstrated before commercial-scale activity commences.

45. A couple of questions were raised after the presentation. One was, 'For fishery surveys, how were the various eel species identified?' The response was 'By morphology. *A. marmorata* is easy to recognise. *A. megastoma* were not found. The 2015 survey was a creel census from the middle reach of the Sigatoka River down to the river mouth.'

46. Lekima Copeland commented that *A. megastoma* is very rarely found in surveys in Fiji. In New Caledonia, *A. megastoma* occurs in the very upper reaches of rivers, and in small streams in the mountains. There will be a bias in the national data if the upper reaches are not surveyed. However, these upper reaches are inaccessible.

[5] Beumer J.P. 1984. The eel resources of Fiji. Study Tour Report QS 85010. Queensland Department of Primary Industries. Brisbane. 33 p.



Typical eel farms in Kagoshima, Japan:

h Eel tanks enclosed inside green houses that use heated water for winter grow-out.

i An open-water eel pond used for summer grow-out.

j Size-grading of farmed Japanese eels for market.
(Photos: K. Tsukamoto)

47. Another question that was raised was, 'Are there any plans to do more survey work on eels?' This participant felt that the fishery survey work on eels was more important than the work on aquaculture. In response, it was clarified that, 'For MoFF, eels are already a component of general inland fisheries surveys by creel census. There is room for a PhD thesis here, if a student wanted to invest time in a more intensive study of adult eels in Fiji.'

The importance of eels in Samoa

48. The next presentation was on the 'Importance of eels in Samoa, and was given by Ulusapeti Tiitii, Manager of Coastal Fisheries and Aquaculture under the Ministry of Agriculture and Fisheries in Samoa. Eels are culturally significant in Samoa, but the level of utilisation is low so not much is done regarding fisheries management.

49. Samoa's Ministry of Agriculture and Fisheries empowering statutes require that aquaculture development be promoted in a sustainable way. The goal of government is to add to natural fisheries production through aquaculture, and it is open to exploring ideas about new species that will add value to Samoa's natural resources.

50. Freshwater eels are given a 'low priority' ranking in Samoa's current National Aquaculture Plan[6], after a consultative process in which aquaculture commodity rankings were determined by a combination of their technical 'feasibility' and their economic and social 'impact'. The lack of knowledge about the aquaculture of eels, and the absence in Samoa of suitable culture facilities and feed products for eels, are why eel aquaculture has received a low score for 'feasibility'. This score will undoubtedly increase as more knowledge is gained. The 'impact' score of eels is medium or high because people in Samoa regard eels as high value. Eels are a delicacy, and a high status food item reserved for chiefs and pastors.

51. Samoa also has the ancient legend of 'Sina and the eel', and there is a site on Savaii Island where this legend is said to have taken place.

52. There is some low intensity eel aquaculture occurring in Samoa, where two tilapia farmers have purposely introduced eels into their tilapia ponds.

53. Foreign investors from China have approached Samoa Fisheries, seeking information about glass eels, but there are no data available on which to formulate any response. There is a need to know more though because politicians are now interested in eels. Knowledge gaps for eels in Samoa include: the number of eel species present; the need for scientific and economic data, as well as traditional knowledge about eels; awareness raising about threats to eels (many people think that eels 'come from the mud'); and a baseline survey on population abundance and seasons of migration.

54. Samoa Fisheries wants to increase its capacity with regard to eels and eel aquaculture through: better understanding the life cycle; collection of different stages; farming techniques; feeds and feeding; and pond design.

55. Samoa currently does not have a policy regarding the export of eels, as they do for sea cucumbers. For sea cucumbers, the policy is that only sea cucumber produced by aquaculture can be exported, and only a set percentage of this aquaculture harvest may be exported.

[6] Samoa Aquaculture Management and Development Plan 2013–2018. Ministry of Agriculture and Fisheries, Government of Samoa/Secretariat of the Pacific Community SPC. Noumea, New Caledonia. 20 p.

56. Several questions were raised after the presentation regarding the number of rivers in Samoa, the sale of eels in markets, and methods for cooking eels. It was explained that there are many rivers in Samoa, and there is a lot of potential for glass eel capture. Eels are not sold in markets in Samoa; if they were, Samoa Fisheries would have details from market surveys. Likewise, landings are also not reported in market data. People fish for them in rural areas where eels are a high status food item that appear in traditional and church functions. In Samoa, eels are cooked by wrapping them in banana leaves and baking them in an *umu* (earth oven of hot stones). No coconut cream is needed (unlike for marine conger eel) because freshwater eels are already very oily.

Plenary discussion

57. In answer to a query directed to participants representing environmental non-governmental organisations based in Fiji, World Wildlife Fund (WWF) responded that the conservation of eels is not a big part of what they do; however, it is a component of the environment and biota that they are committed to protecting so they are keen to learn more. WWF has a freshwater mussel (*kai*) project in Ba River, onto which eel work could be added if any student is interested in sharing logistics.

58. The main point to emerge about the farming of eels is that there is more to it than simply adding juvenile eels to tilapia ponds. To farm eels efficiently on a commercial scale, it is necessary to target the glass eel stage and capture them in large quantities. Unlike with the capture of juveniles, glass eel capture provides eels that are of the same age class, which helps to ensure consistency of size and growth characteristics. Glass eels traditionally were started on a live diet (such as brine shrimp) and then weaned onto formulated artificial food, while stocked into specialised culture systems at the correct density to reduce cannibalism. In Japan, an artificial diet for glass eels has recently been developed to replace live brine shrimp.

59. The above aquaculture methods could be introduced to the Pacific by technology transfer from Asia so it is not an insurmountable problem; however, it will require a large investment. Before such an investment is deemed justifiable, the acceptability of South Pacific freshwater eels in Asian markets needs to be verified. Both the aquaculture grow-out characteristics and the market characteristics of the main South Pacific eels are as yet untested. It is prudent to start from the market and work back to production. We should not begin by producing eels, and then look around for a market. As with all aquaculture, any project to commercialise South Pacific eels should start from the market and work its way back to production.

Preliminary results from one year of glass eel sampling in a Fiji river

60. Chinthaka Hewavitarane, a PhD candidate at the University of Kyushu in Japan, gave a presentation on the 'Preliminary results from one year of glass eel sampling in a Fiji river mouth, 2015–2016'. Mr Hewavitarane reported that there are currently no scientific records of glass eel or elver migrations in Fiji Islands. There has not yet been any systematic scientific study of eels in Fiji. In other regions of the world, eels are now endangered, and there is a need to conduct research on eels in Fiji before there becomes pressure on this resource.

61. Mr Hewavitarane's topic for PhD study focuses on species composition, abundance, and seasonality of glass eel recruitment at one river mouth in Fiji. Glass eel recruitment is influenced by two main factors: darkness and high tide. Because of the darkness factor, sampling for his study was done only at night, and only during a new moon and full moon. Of the approximately 2,000 glass eels he has caught in total, only 8 were caught during a full moon. This means that, in practice, the time period when catch levels in Fiji make glass eel fishing worthwhile is limited to the new moon period, which is only three or four nights every month.

62. Because of the tide factor, glass eel fishing is limited to only two hours (somewhere between 17:00 and 21:00) on each of those three or four nights. This is because in Fiji, there is only a short period at night when a rising tide coincides with a new moon, and this rising tide always occurs in the early evening. Recruitment decreases after the slack water period of a high tide, when the tide ebbs again.

63. There are always large numbers of crablets and freshwater prawns in the water column at the same time as glass eel recruitment, and this is also the case in Japan.

64. Mr Hewavitarane described the methods he used for processing his glass eel catch to obtain scientific data. These methods were also demonstrated in the laboratory practical session of the workshop so that participants could see first-hand what is involved in adopting eel research techniques in their own institutions.

65. The first step of a morphometric analysis is to measure fin lengths and total body length. There are both shortfin and longfin eels present in Fiji. Eels are anaesthetised with clove oil to render them inert but alive and flexible. Measurements are made by laying each eel out straight on a graduated grid under a dissecting microscope. Body pigmentation is photographed as a further aid to species identification. The glass eel developmental stage is identified according to morphological features originally described by Bertin (1956)[7]. The traditional technique of vertebral counts to identify eels to species level is no longer used because of overlaps in counts between specimens of some species. That method has been replaced by the preservation of each eel in high-grade ethanol for genetic analysis to confirm its species. While still fresh, the eel is weighed on an accurate balance after careful blotting to remove excess water. The body weight is combined with body length to calculate a condition index ('fatness'). After preservation in ethanol, one otolith bone is extracted and mounted on a glass slide in order to count the number of daily growth rings. This is done to determine the age of each glass eel when it made landfall. From ocean current modelling, it is possible to use this age and the capture location to estimate roughly where in the ocean each eel was spawned and hatched.

66. On the basis of morphology of the eels in Chinthaka's samples, it initially appeared that six species of freshwater eel recruit into Fiji. The evidence for this was from a combination of anal and dorsal fin ratio and body pigmentation, and was not from just one specimen but from several. However, morphology is not always accurate in identifying glass eels to the species level, so confirmation of this must always await the outcome of genetic analysis. On the basis of genetic evidence, all of the specimens collected (including 'outlier' specimens) could be assigned to one of three species — *A. marmorata*, *A. obscura* and *A. megastoma* — with specimens showing a high degree of morphological variation within each species.

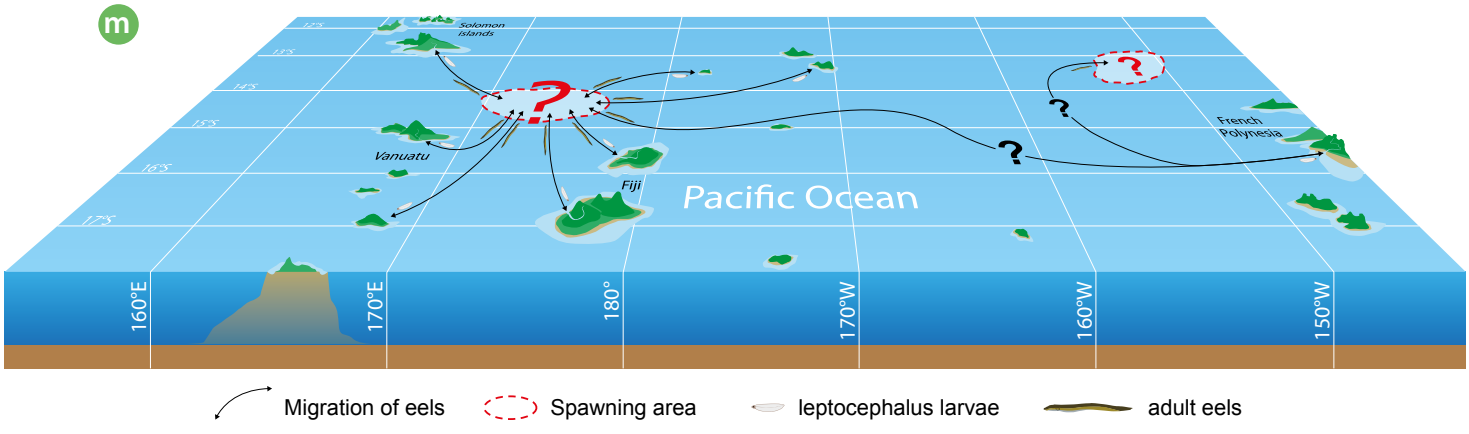
67. The recruitment of glass eels in Fiji is characterised by a steady background level of 'trickle recruitment' year round, combined with large seasonal peaks in recruitment. The season for these peaks is different between the three main species of Fijian eels. *A. marmorata* (the most common eel in Fiji) has two main seasons for recruitment, one

[7] Based on Bertin L. 1956. Eels — a biological study. Cleaver-Hume Press, London. Cited in Fukuda 2010. Accessible at http://repository.dl.itc.u-tokyo.ac.jp/dspace/handle/2261/49079.

k Sampling of adult yellow eels in Wailoku Stream near Suva, Fiji, for population study. (Photo: T. Pickering)

l One method for catching glass eels in Fiji, at high tide with a torch and hand dip net, at a place where a road bridge crosses a river. (Photo: C. Hewavitarane)

m South Pacific freshwater eels make long migrations for breeding at open-ocean spawning grounds in very precise locations which are still unknown, and their larvae migrate all the way back to the various island groups. (Illustration: B. Colas)



in September/October and the other in April. *A. obscura* (the most marketable of our species in Asia) recruits mainly in February/April. *A. megastoma* (the rarest of the three eels in Fiji) arrives in October–December.

68. Of the one year's catch of glass eels in 2015–2016, 57% consisted of *A. obscura*, 40% *A. marmorata*, and the remaining 3% *A. megastoma*.

69. Why do the three species in Fiji recruit at different times? What is recruitment linked to? Preliminary statistical analyses indicate that the strongest correlations between recruitment levels and environmental parameters are water temperature and rainfall. As soon as the rainy season begins after the dry season, glass eel recruitment is observed. The separation of the three species into three different seasons may reflect different water temperature preferences for recruitment.

70. A comment was made that in French Polynesia, the glass eel catch is mostly *A. marmorata*. There are some *A. obscura*, and hardly any *A. megastoma*.

71. A participant asked what the threats to *A. japonica* were, and it was explained that overfishing of glass eels and barriers to migration (although this has been improved in Japan) are the main threats.

72. Another participant mentioned the peak in species recruitment, and asked what the trigger was for such clear peaks, and which factor may be most prominent to form such peaks. Chinthaka's analysis was initially one of comparing environmental parameters within each month with other months, and this showed no differences between months. When he instead grouped the environmental data by seasons, and compared peak season data with non-peak season data, then temperature emerged as the main factor linked to recruitment. Rainfall emerged as the second most important factor. Recruitment occurs in the wetter months, and time-of-sunset affected one species only. It was also explained that the cause of trickle recruitment between the peaks cannot be explained.

73. A participant asked whether El Niño influenced eel recruitment. The response was: Possibly. If so, then this one year of sampling in Fiji during 2015–2016 represents a worst case scenario for Fiji eel recruitment because over the last 12 months, there has been a strong El Niño event that is only just now ending. In Fiji there is always less rainfall during El Niño events.

74. The presenter explained that the data were only from one river. Other rivers may give different results and different percentages. Fiji has a dry western side and a wet eastern side. Tagging silver eels should come next as a priority for research.

The evolution of seasonality in anguillid eels

75. Katsumi Tsukamoto from Nihon University in Japan gave a presentation on the 'Evolution of seasonality in anguillid eels: from the tropics to temperate'. He reported that South Pacific eels are included in the group of 'tropical eels', and that anguillid eels are of tropical deep sea origin, and are closely related to the mega-mouth eels of the very deep sea abyss. These evolved when shallow water marine eels moved to deep sea mid-water and adapted to open ocean environments. Some planktonic larvae were transported to

the coastal waters and then invaded rivers to become catadromous eels, living inland but still linked to the deep sea for spawning. This is the evolutionary history that explains the long migrations of freshwater eels from the deep sea to land and back again.

76. The presenter reported that the big research question for anguillid eels is 'Where do they spawn?' For South Pacific tropical eels, this is still a mystery. Johannes Schmidt is the 'father' of eel research because in the 1930s he proved a link between adult eels in Europe and leptocephali larvae caught in the Sargasso Sea in the northwest Atlantic near North America. The closer his research vessel steamed toward Europe from North America, the larger and older the specimens of leptocephali were that he caught in his plankton net.

77. In the 1990s Japanese scientists repeated this process for *Anguilla japonica,* the Japanese eel. By searching for leptocephali of smaller size and younger age, they estimated a 'box' of sea area west of Guam where the Japanese eel must breed. This finding was so significant that it was published as a cover-story paper in *Nature* [8]. By searching this sea area they were next able to collect adult eels, and finally, fertilised eggs of eels in plankton samples.

78. The two most important events in an animal's life are growth and reproduction. For animals where the growth habitat is different from the reproduction habitat, 'migration' is the transition from one habitat to the other. We call this a 'migration loop' that connects Habitat A with Habitat B. Each species of eel has a specific migration loop. Each population of that species also has one migration loop.

79. For eels, their growth habitat is very big and widespread. This is for carrying capacity reasons, and to avoid competition with each other. However, their reproductive habitat is very small and restricted. This is so that the eels will be able to find a partner for mating.

80. Among salmon, it is known that some fish are 'river residents' that never migrate out to sea and follow the usual migration route. It has been proposed that eels must, therefore, have 'sea residents', which choose to never migrate inland and instead remain living in coastal waters. Such eels termed 'sea eels' have been discovered.

81. Present day anguillid eel biogeography and speciation can be explained by the Tethys Sea hypothesis that was obtained based on the molecular phylogenetic tree of all anguillid eels in the world. Eels originated near Borneo 100 million years ago in the Cretaceous period. Continental drift made openings out from the ancient Tethys Sea, which allowed eels to radiate from Southeast Asia to Europe, North America and the South Pacific, but not to South America or to the west coast of Africa. The study of South Pacific tropical eels can, therefore, provide keys to understanding eel evolution overall.

82. Eel spawning habitats are small, and conservative. Eels cannot move their spawning areas in the tropics. The success of their mating and migration depends on these spawning areas remaining the same. Such areas need protection.

83. A wide range of growth habitat for eels means that eel migration loops will also be large.

84. So far, we only know of three spawning areas for anguillid eels. *Anguilla anguilla* and *A. rostrata* spawn in the Sargasso Sea area of the Atlantic Ocean. *A. japonica* spawns around the sea mount area near the edge of the Mariana Trench. *A. celebesensis* and *A. borneensis* spawns in the relatively shallow Celebes Sea and Tomini Bay near Borneo.

85. Seasonality of eel spawning can be tracked in both annual and daily growth rings seen in the eel otolith. These rings allow back calculation from the date of capture to the eel's

[8] Tsukamoto K. 1992. Discovery of the spawning area for the Japanese eel. Nature 356:789–791.

date of hatching from its egg. Otolith data tells us that the spawning season for Japanese eels is in the Northern Hemisphere summer. Japanese glass eels recruit back to land in winter, after a six-month transportation by current through open ocean. Silver eels depart from Japan in winter, and begin a six-month migration to their spawning area near Guam. The period from May to July is the peak spawning period, according to ageing data of leptocephalus otoliths. But the leptocephali caught within this three-month period fall into three different age groups. These correspond to hatch dates around each of the three new moon periods between May and July. In other words, spawning is linked to lunar cycles. There is synchronised spawning by adult eels during the new moon period, over a three-month interval each year.

86. H.K. Sugeha[9] has described Indonesian eel spawning, which also shows a clear lunar cycle and a nocturnal effect. Recruitment of glass eels is almost all year in Indonesia, but has seasonal peaks. Tropical eels appear to have a more flexible behaviour for spawning and recruitment compared with temperate eels.

87. Japanese silver eels become reproductive with early stage of ripe gonads during October to December. There is clear seasonality in gonad maturation. The eels start their migration at a very immature state (GSI: less than ca. 4), and they swim for 2,000 km or more. When sexually mature, half of the female eel's body weight is eggs! Lunar phase and wind stress are the environmental triggers for migration. It takes around half a year or less to reach the spawning ground from Japan. Leptocephali have a half year of migration all the way to their growth habitat in east Asia. It is a tight and strictly defined travel schedule. Males and females need to somehow meet each other in the vastness of the dark ocean.

88. The duration of downstream migration for tropical eels is longer. Less is known about tropical eels in terms of scientific knowledge about seasonality in spawning, glass eel recruitment and adult migration than for other eels.

89. The two vital keys to long distance migration of eels is: i) the long distance dispersal ability of leptocephali, and ii) the persistence and permanence of spawning sites. Eel spawning, therefore, occurs at a pin-point, species-specific spawning site. How do eels find this site in the huge ocean? Is it by smell? Do they follow a specific current or eddy?

90. Understanding the meaning of long migration by eels is key to understanding eel fisheries stock management, and the availability of glass eels for aquaculture.

91. The last big objective of eel research is understanding the spawning schedule of adult eels ('silvering'). Silver eels exhibit higher activity and migratory 'restlessness' behaviour than yellow eels. Male hormone 11-KT is the trigger for the silvering of yellow eels. A water temperature decrease of 25°C to 15°C causes 11-KT elevation in eels. Surgical attachment of a pop-up tag enables the silver eel migration route to be tracked by satellite. However, the high cost of such tags, a high loss rate of tags after attachment, and the high energetic cost for eels to swim with a large tag attached means that pop-up tagging has been successful only in a few instances.

92. Japanese eels can now be bred and reared in captivity. However, the egg quality of artificially spawned eels is low. Both larval diets and rearing systems need further development. Repeated hormone injections are needed to trigger maturation and spawning, hence low egg quality. The cost of each glass eel is too high for hatchery rearing to be a viable commercial process. Eel aquaculture remains dependent on fishery-based culture of glass eels from the wild. Meanwhile, Northern Hemisphere glass eel fisheries are all decreasing.

[9] Sugeha H.Y., Arai T., Miller M.J., Limbong D., Tsukamoto K. 2001. Inshore migration of the tropical eels, *Anguilla* spp., recruiting to the Poigar River estuary on Sulawesi Island. Marine Ecology Progress Series 221:233–243.

n IKMT net being deployed from the trawl deck of the University of Tokyo research vessel Hakuho Maru. (Photo: M Kuroki)

o A juvenile of *Anguilla marmorata* is caught in the scoop net after being brought out of hiding by the electro-fishing gear. (Photo: T. Pickering)

p Deployment at Opunohu river mouth in Moorea of a fine-mesh net of the type used for scientific sampling of glass eels to estimate eel recruitment. (Photo: T. Pickering)

q A dish full of eel leptocephalus larvae from a mixture of eel families, including conger and moray eels, captured in mid-ocean between Fiji and Vanuatu by scientists aboard Hakuho Maru. (Photo: M Miller)

93. Eel conservation is important for natural, social and cultural reasons. The best way to conserve eels is through interdisciplinary scientific study. Nihon University has an eel laboratory that dispatches a travelling classroom for schools. The objective is to raise awareness among the Japanese public (especially school children) about eel research and threats to eels.

94. At the end of the presentation, a number of questions were asked and answered by the presenter.

- *Where do sea eels live? Is this an adaptation to guard against inland habitat degradation? Is it only for A. japonica?* Sea eels do not migrate upstream but instead stay in coastal seas or estuaries their whole life. They can survive there even if river mouths are blocked. It is not only *A. japonica*. Tropical eels do this too, but much less than temperate eels. Temperate coastal waters are more productive than tropical waters. It is linked to food availability. In the sampling area at Navua in Fiji, there is a large *A. obscura* that is a permanent resident of salt water.
- *How can multiple spawning areas for A. marmorata be explained?* Different genetic populations have their own spawning areas.
- *Is it a cause, or a consequence?* It is the prelude to speciation. Some eels could spawn in another (new) place someday.
- *Will the seasonality of eels be affected by climate change and will there be a major shift*? The presenter said this was an area that needs study.
- *How is the pop-up tag attached to a silver eel?* A harness is attached to the eel by surgery. After recovery, the tag is attached and the eel is released.
- *Where is the best place to set fyke nets for silver eels? At the surface of a river, or down deep?* At the surface. 'Migration restlessness' of silver eels involves more surface swimming behaviour than that of yellow eels.

Distribution and migration of tropical eel leptocephali in the South Pacific

95. Mari Kuroki of the University of Tokyo in Japan gave a presentation on the 'Distribution and migration of tropical eel leptocephali in the South Pacific'. Leptocephali, a common fish larval form of suborder Elopomorpha, are unique marine organisms. Their morphology does not look like other fish larvae. It is easy to find their leaf-like transparent bodies in plankton samples. The morphological characteristics of leptocephali are different among families of Anguilliformes (eels). A variety of characteristics, such as body shape, eyes, teeth, gut type, number of vertebrae, number of muscle myomeres, and pigmentation patterns, are used for the identification of eel leptocephali to the family level (freshwater eels Anguillidae, conger eels Congridae, moray eels Muranidae, etc).

96. The body size of anguillid leptocephali (freshwater eels) is about 5–80 mm, and the total number of vertebrae ranges from 100 to 120. Their morphology is distinctive because they lack any pigmentation, except for small-sized young larvae of about 5–10 mm, which have tiny pigmentations on the tail. They have a straight gut that extends about 75% of the body length. The number of muscle myomeres from the head to the last vertical blood vessel is 41–45. They have round eyes and a round caudal fin.

97. Two types, 'shortfin' and 'longfin', are seen in anguillid leptocephali, distinguishable by the total number of vertebrae and by the length between dorsal fin and anal fin (as for adult eels of each species). However it is seldom possible to identify anguillid leptocephali to the species level without the use of genetic tools. This is especially true of tropical eels because some (including the South Pacific species) have sympatric distributions, but their morphological characteristics (such as total myomere counts) overlap too much to allow specimens to be separated into species.[10]

98. Identification using genetics is useful for leptocephali, because there are 19 species/subspecies of anguillid eels whose leptocephali stages all look very similar. Genetic study of leptocephali caught in the open ocean has revealed the existence of new undiscovered species of eel that otherwise would not have been recognised purely from the morphology of their adult stages. One example is *Anguilla luzonensis*, which was discovered recently in the northern Philippines. Because of genetic evidence obtained from leptocephali collected in the western North Pacific Ocean, a search for this eel was made on land. When found, it was described as a new species.

99. The distribution and migration of anguillid leptocephali in the Indo-Pacific have been studied during oceanic research cruises starting from 1995. From catches of small leptocephali (around 10 mm), the rough locations of four spawning areas of the tropical eels *A. marmorata*, *A. celebesensis*, *A. borneensis* and *A. interioris* have been determined within the Indonesian archipelago. Migration scales of these tropical eels is much smaller, being either 80–300 km or 1,000–2,000 km, depending on the population, when compared with the 2,000–8,000 km migrations of temperate eels such as the Japanese eel *A. japonica*, European eel *A. anguilla*, and American eel *A. rostrata*. Tropical eel leptocephali also have much higher growth rates (based on otolith analyses), and metamorphose into glass eels at a younger age and at a smaller size, compared with temperate eels. Several cruise surveys have been conducted by the Japanese research vessel R/V *Hakuho Maru* (in 1995, 2000, 2005 and 2013). But the leptocephalus collection from South Pacific waters is still very limited and is insufficient for determining their early life history. This means it is difficult to evaluate the resources available for utilisation of tropical eels. Globally, populations of eels are declining, and some species face a real threat of extinction. Effective conservation strategies and measures are required urgently.

100. The main biological questions that need answers are: i) Where are the spawning areas?; ii) Where do eels migrate in the open ocean?; iii) Is the migration pattern of South Pacific eels different from that of other temperate and tropical species?; iv) How do eels grow and recruit to freshwater habitats in the South Pacific?; v) How did the evolution of anguillid eels occur?

101. The science needed to answer these questions will then also help to answer questions about the sustainable utilisation of eels: i) Does enough population exist to utilise?; ii) How do we manage sustainable utilisation?; iii) What is the most appropriate strategy for conservation?

102. In mid-2016, an oceanographic sampling survey will be conducted to study the spawning and migration ecology of both tropical and temperate freshwater eels in the South Pacific and the western North Pacific, and to learn about anguillid eel spawning areas and the distribution of their larvae. The dispersion and transportation of their eggs and larvae will also be studied in relation to the currents in these regions. This cruise will include four legs: from Japan to New Caledonia (Leg 1: 11 July–1 Aug.), from New Caledonia to American Samoa (Leg 2: 4 Aug.–17 Aug.), from American Samoa to French Polynesia (Leg 3: 20 Aug.–12 Sept.), and from French Polynesia to Japan (Leg 4: 16 Sept.–4 Oct.).

[10] Miller M.J. and Tsukamoto K. 2004. An introduction to leptocephali: biology and identification. Ocean Research Institute, The University of Tokyo, Tokyo, viii+96 pp.

103. The main objective is to reveal the spawning and migratory ecology and population fluctuation mechanism of anguillid eels. The migration routes of each species will be inferred by the geographic distribution of leptocephali, their sizes (and ages), and ocean currents. In addition, if very young pre-leptocephali larvae or eel eggs are discovered, this may help to reveal the location of South Pacific eel spawning areas.

104. For the research objectives above, eel eggs and larvae will be collected using an IKMT (Isaacs-Kidd Midwater Trawl) plankton net or an ORI (Ocean Research Institute) plankton net (large plankton net). The hydrographic characteristics and topographic structure of the sampling area will also be determined using a CTD (conductivity, temperature, depth profiler) with water sampler, echo sounder, and ADCP (acoustic doppler current profiler) so that biological data can be understood together with the oceanographic features of the spawning locations and larval distribution areas.

105. Several related questions were raised after the presentation*: Where is it predicted that the most leptocephali will be caught on the research cruise in the South Pacific? On Legs 2 or 3? And, what species will be caught?* For the survey area on Leg 2, in the past we have collected 182 anguillid leptocephali at longitudes from 160E to 175E during the winter of 1995. Therefore, we expect that we will catch many anguillid larvae just as we did in the 1995 cruise. On the other hand, the survey area on Leg 3 (longitudes 170W to 140W) will be the first trial of a sea area that has never been surveyed for leptocephali, so we cannot predict. Based on preliminary results of the aging analysis of glass eels collected in Tahiti, the survey season will be just after hatching season. So, we may be able to collect small anguillid larvae around there.

106. We expect that, in total, there are up to seven species of freshwater eels that can be caught as leptocephalus larvae in the waters of the South Pacific: *A. marmorata*, *A. bicolor pacifica*, *A. megastoma*, *A. obscura*, *A. australis*, *A. reinhardtii* and *A. dieffenbachii*. No one has ever collected a single larva of *A. dieffenbachii,* which is the endemic giant eel of New Zealand.

New data on eels in French Polynesia

107. Pierre Sasal with CNRS CRIOBE on Moorea in French Polynesia presented 'Some new data on eels in French Polynesia'. The work done so far in French Polynesia is an interesting case study that demonstrates there are some quite simple things that can be done to research FW eels in the South Pacific. Pierre started off by deploying a glass eel net in the Opunohu river mouth next to his lab, though he had no success at first because glass eels were out-of-season. French Polynesia is relatively isolated and covers a large area of ocean. Moorea is 5,000 km from Noumea, and is at the very far edge of the geographical distribution for anguillids.

108. From genetic evidence it appears that *A. marmorata* has about four populations in the Pacific, with two of these in the South Pacific (east and west). There are two populations of *A. megastoma* in the South Pacific. Both species are regarded as 'data deficient' as is *A. obscura*, according to IUCN's Red List.[11],[12],[13] There is very little information about biomass, population structure, recruitment and life cycle.

[11] Giant marbled eel *Anguilla marmorata*. IUCN Red List of Threatened Species assessment, http://www.iucnredlist.org/details/166189/0
[12] Polynesian longfin eel *Anguilla megastoma.* IUCN Red List of Threatened Species assessment, http://www.iucnredlist.org/details/196301/0
[13] Polynesian longfin eel *Anguilla megastoma.* IUCN Red List of Threatened Species assessment, http://www.iucnredlist.org/details/196301/0

r Workshop participants are introduced to electro-fishing gear by Pierre Sasal, Chinthaka Hewavitarane and Lekima Copeland (on left, holding nets). (Photo: T. Pickering)

s An eel is spotted beneath the overhang of the stream bank. (Photo: T. Pickering)

t Inspecting the glass eel catch the next day, at Opunohu river mouth. (Photo: T Pickering)

109. As a first step, it is necessary to sample rivers to find out the abundance and population structure of adult eels. This needs to be done periodically to show any trends over time. There are many rivers in the South Pacific and sampling them is time-consuming work. It is necessary to choose just a couple of indicator rivers, and start with those.

110. Dr Sasal described the use of an electro-shocker to sample rivers for adult eels. The eels caught in this way can be identified to the species level, then weighed, their body length measured, and the number of eels captured within a measured distance of river can be counted.

111. The eels caught during sampling can be tagged with electronic pit-tags. This is possible with eels that are 15 g or larger. We can then recapture these in subsequent field surveys. The information provided by the recovery of tags from among the sampled catch allows population density to be estimated (mark-recapture), as well as individual growth rates, and these can be used as indicators of fishery status.

112. The techniques to sample rivers for adult eels using electro-fisher were demonstrated to meeting participants during the field practical session of the workshop, which was conducted at a middle reach of Wailoku Stream near Suva. A demonstration of pit-tagging was done on the eel catch. Once the small electronic tag has been inserted under the skin of the eel using a tag applicator, it could be detected by 'swiping' the eel with a handheld electronic sensor. This sensor is similar to those used in supermarkets to read the price of items from their bar code.

113. In future, any eels caught while fishing or found on-sale in markets can be swiped by the sensor to reveal the tag number. Researchers can then look up the tag number in their logbook to find out the date of tagging, and the length and weight of the eel at the time when it was tagged. By measuring and weighing the eel again after recapture, the eel's growth rate can be estimated. The percentage of tagged eels within the total catch of sampled eels can be used to calculate the total number and biomass of eels in the area.

114. Sampling glass eels is the second step that can be taken to estimate the number and seasonality of eel recruitment to the fishery. Dr Sasal explained how glass eel nets can be deployed in a river mouth to capture glass eels at the moment they arrive at land from the ocean. This technique was also demonstrated in the practical session of the workshop. Estimates of new recruitment to the adult fishery are needed for fisheries stock assessment. For aquaculture, glass eels can be the target of fishing because the hatchery production of eels is still only possible for one species, *A. japonica*, and it is not economically feasible.

115. Results of glass eel sampling in French Polynesia are: i) right now eel populations in French Polynesia are not exploited much; ii) there is a limited distribution area, so the question is whether recruitment is irregular in French Polynesia; iii) there is a large proportion of *A. obscura* in catches from the Austral Islands.

116. French Polynesian glass eels are about 100 days old when caught, and the season for arrival at the river mouth is in December, which means they hatched from their eggs in August. In August 2016, the cruise of Hakuho Maru is scheduled to carry out plankton tows across this area of ocean, so data show that the chances of finding eel leptocephali will be at their greatest in this month.

117. The silvering of eels is an important area to study if we are to fully understand eel migration and reproduction, but it's a difficult area to study. In French Polynesia, the general trend is that glass eel recruitment occurs in the wet season, while the silvering of eels occurs from May to July, and the hatching of leptocephali from eggs occurs from August to November.

118. If we want to sustainably practice aquaculture based on glass eel capture, then this kind of data is needed for all South Pacific countries.

119. For eel conservation, we need to manage threats to eels in rivers, such as overfishing, habitat degradation and barriers to migrations.

120. At the end of Dr Sasal's presentation, several questions were raised.

- *In French Polynesia, glass eel recruitment was quite low. Why?* The position of the Opunohu River is at the bottom of the deep bay, and it's only a small river. But this year, 2016, he observed a big recruitment event. European eel data show large inter-annual variations in glass eel recruitment. It takes time (at least five years) to show recruitment patterns. This is too long a period for a Master's degree or PhD candidate to study it. This is, however, an appropriate job for a fisheries department to carry out because of their ability to perform long-term monitoring.
- *Did you collect glass eels from other places in French Polynesia?* No. It is complicated.
- *For Samoa, would it be useful to construct a questionnaire and ask general information from eel fishers? When you collect eel samples, do you do it at night?* An eel questionaire is very useful, for example, to find out more about silver eels. The questionnaire needs to be well designed, however, and one must be cautious with the questions and answers. Electrofishing is done during the day. In French Polynesia, the glass eel net is deployed during the day and is left in place for 24 hours. This contrasts with Fiji, where Chinthaka collects glass eels for only two hours and only after dark.

Priority needs for research on eels in the South Pacific

121. At the conclusion of the meeting, a plenary discussion was held to reach a consensus among stakeholders present about the most pressing needs for research on eels in the South Pacific. This research is aimed at supporting sustainable management of eels by Pacific Island government and administrations, and addresses both conservation and utilisation objectives. 'Conservation' here includes social and cultural values, in addition to biological ones. Priority rankings were given to place each research topic into a timeframe for implementation, where 'immediate' is during the next two years and 'medium-term' is during the next five years.

122. Implementation of any research plan is subject to funding. There is increasing interest in South Pacific eels from fisheries administrations, from the private-sector, from international researchers, and from local tertiary institutions. This report explains how and where best to engage in South Pacific eel research in order to make progress. It also sets out the current state of knowledge about South Pacific eels for the benefit of anyone who is new to this subject. It is our hope that this information will spark the interest of post-graduate students to take up eel research topics.

123. This workshop on eels, and the preceding ones, have brought together a group of people who can now be loosely defined as a 'South Pacific Eels Group'. These people will continue to stay in touch, forge collaborative links, coordinate research activities, make joint applications for funding, and (as and when funding becomes available) tackle these research topics in a logical sequence. In this way, we can steadily increase our knowledge for sustainable management of the world's 'last frontier' for freshwater eels.

The table below indicates research needs and priorities for South Pacific freshwater eels.

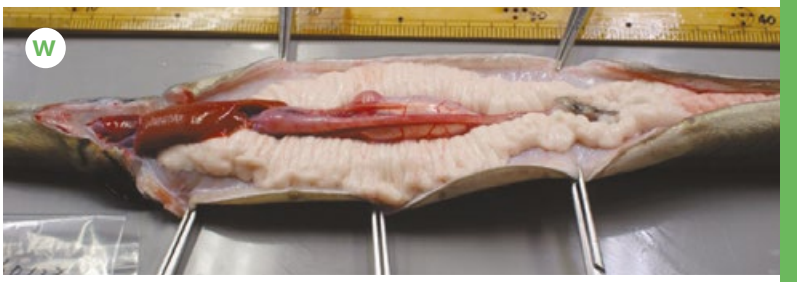
SECTOR	RESEARCH TOPIC	IMMEDIATE	MEDIUM TERM
Conservation and fisheries management	Confirm at the national level the species of eels actually present as adults in rivers.	✗	
	Develop an appropriate and gender-sensitive questionnaire to collect knowledge held by fishers about eels (e.g. the season for silvering), which can help to direct scientific research and fisheries management efforts.	✗	
	Estimate trends through time in population density and biomass of eels in selected indicator rivers, via regular surveys using electro-fishing. Develop a manual for eel population survey techniques that can be incorporated into any general fisheries survey.		✗
	Carry out tagging of eels caught during electrofishing surveys for mark and recapture population studies. Find out the age structure and describe the parasites of adult eel populations (possible PhD topic).		✗
	Capture and study silver eels in a South Pacific location (possible PhD topic).		✗
	Find out whether each South Pacific eel species is a single inter-breeding (panmictic) population, or is composed of two or more reproductively isolated populations by using genetic tools to compare glass eels collected from multiple Pacific Island locations in the same new moon period.	✗	
	Review the need for science-based regulations for conservation and management of freshwater eels within Pacific Island government and administrations. Develop national Freshwater Eel Management Plans (the same concept as Sea Cucumber Management Plans) for eel conservation and utilisation. Promote awareness to increase knowledge and dispel misconceptions about eels (e.g. that they do not just 'come from the mud').	✗	
	Conduct a review to forecast possible impacts of climate change or natural disasters on South Pacific freshwater eels.	✗	
Aquaculture	Conduct regular surveys to estimate glass eel abundance, geographical distribution, and seasonality (led by government, and supported by private sector).		
	Develop science-based regulations, guidelines or codes of practice for the sustainable collection of glass eels for aquaculture.	✗	
	Transfer and adapt suitable aquaculture technology and grow-out system design that is appropriate for the culture characteristics of South Pacific eel species.		✗
	Assess different feed sources (both local and imported) for farmed eels, to find the most cost-effective feed source for South Pacific eel aquaculture.		✗
	Conduct market research, to find out which market requirements are best matched by the characteristics of South Pacific eel species.	✗	
Sociological and cultural values	Document stories and legends that feature eels, traditional knowledge about uses of eels, and significant eel sites, both for their own sake and as a guide for conservation and management (possible MSc or PhD study).	✗	
	Find out the contribution and importance of South Pacific freshwater eels in subsistence fisheries.		✗

u Yellow eel *A. marmorata* captured by electrofisher in Wailoku Stream for measurement and release. (Photo: T. Pickering)

v A silver eel, showing the body changes for oceanic migration to the breeding ground (larger eyes, larger pectoral fins, and silver belly). (Photo: P. Sasal)

w A Japanese silver eel artificially brought to maturity in captivity, dissected to show the large body-space taken up by gonad by the time it is ready for spawning. (Photo: K Tsukamoto)

x Eel migration simulator tanks, specially developed in Japan for breeding *A. japonica* in captivity. (Photo: K Tsukamoto)



Appendix 1: Meeting agenda

Monday 13 June 2016

09:30–10:00	Registration
10:00–10:30	Introduction to the conference (Prof. Ciro Rico, USP, Fiji; Dr Tim Pickering, SPC, Fiji; Dr Pierre Sasal, CNRS CRIOBE, French Polynesia)
10:30–11:15	The life cycle of eels: what do we know? (Dr Pierre Sasal, CNRS CRIOBE Moorea)
11:15–11:45	Overview of the cultural and subsistence aspects of eels for Fiji's indigenous people (Mr Lekima Copeland, Fiji)
11:45–12:15	Private Sector perspective about eels in Fiji (Mr Ah Rum Song, Grace Road Group)
12:15–13:30	**Lunch Break**
13:30–14:00	Status of FW eel resources in Fiji: Insights from MoFF resource inventories, market data, and enquiries received about exploitation (Mr. Shalendra Singh, PFO Aquaculture, MoFF, Fiji)
14:00–14:30	Importance of eels in Samoa (Ms Ulusapeti Tiitii, Ministry of Agriculture and Fisheries, Samoa)
15:00–16:00	Plenary discussion

Tuesday 14 June 2016

09:00–09:45	Preliminary results from one year of glass eel sampling in a Fiji river mouth 2015-2016 (Mr Chinthaka Hewavitarane, PhD Student)
09:45–10:15	**Coffee break**
10:15–11:00	Evolution of seasonality in anguillid eels: From the tropic to temperate (Prof. Katsumi Tsukamoto, Nihon University)
11:00–12:15	Practical session 1: Collecting and processing glass eels – a demonstration of scientific techniques.
12:15–13:30	**Lunch Break**
13:30–14:15	Distribution and migration of tropical eel leptocephalii in the South Pacific. (Dr Mari Kuroki, University of Tokyo)
14:15–15:00	Some new data on eels in French Polynesia (Dr Pierre Sasal, CNRS CRIOBE Moorea)
15:00–16:30	Plenary Discussion: Research needs for eels in the South Pacific region, and future collaborative projects.

Wednesday 15 June 2016

09:00–12:15	Practical session 2: Deployment of net in river mouth for glass eel collection.
12:15–13:30	**Lunch Break**
13:00–15:45	Practical session 3: Electrofishing and electronic tagging of juvenile eels in rivers for population studies.

Appendix 2: Participant list

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South Pacific freshwater eel workshop participants