Case studies on the **impact** of aquatic exotic species in the **Pacific**

Prepared by Ruth García-Gómez, Michel Bermudes and Tim Pickering of the Aquaculture section of the Pacific Community

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Pacific Community
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1. Introduction to the topic

The Pacific Island region hosts 22 countries and territories with combined exclusive economic zones greater than 27 million square kilometres (km^2), which among others, yields more than 30% of the world's tuna. Yet land comprises only 2% of the area of the combined jurisdictions of all Pacific Island countries and territories (PICTs).

Figure 1. Map of the Pacific Island Countries and Territories (PICTs)

Surrounded by this vast ocean, the population of the Pacific region has relied on the sea as its main source for food and subsistence. Despite the tiny percentage of land mass in the region, some PICTs, and especially the high and larger islands, have sizeable freshwater catchments that form the basis of traditional fisheries throughout the Pacific (e.g., native freshwater prawns).

Because seafood sourced from the sea and inland waters has been such an integral part of island life throughout the tropical Pacific, fisheries and aquaculture make vital contributions to economic development, government revenue, food security and livelihoods. In recent years, licence fees from distant water fishing nations (DWFNs) have provided 3–40% of government revenue for seven Pacific Island countries and territories (PICTs), and fishing by national industrial fleets and/or fish processing have contributed 3–22% of gross domestic product (GDP) in five PICTs. Small-scale coastal fisheries have also provided 2–17% of GDP in five PICTs.

The contributions of fisheries to the formal economies of PICTs are matched by the role fisheries and aquaculture play in helping to provide good nutrition and livelihoods across the region.

Fish is a cornerstone of food security for the people of the tropical Pacific – fish provide 50–90% of animal protein in the diet of coastal communities across a broad spectrum of PICTs, and national fish consumption per person in many PICTs is more than 3–4 times the global average.

In rural areas, much of this fish (60–90%) is caught through subsistence fishing.

Many people in the Pacific also catch and sell fish – an average of 47% of households in representative coastal communities in 17 PICTs derive either their first or second income in this way. While industrial fishing and processing operations provide more than 12,000 jobs, aquaculture employs more than 6000 people and supplies another 10,000 households with fish to eat or sell.

2. Scope of the study

The aquaculture sector has developed remarkably in recent years in the Pacific region, despite remaining the least developed and productive by world standards. Nevertheless, aquaculture already makes a significant contributions to wealth and food security in many countries (e.g., tilapia in PNG, shrimp in New Caledonia, seaweed in the Solomon Islands). The sector has a crucial role to play and particularly in vulnerable and isolated local communities where it can provide a solution to better nutrition, income opportunities, gender balance and the improved management of coastal fisheries that are being overexploited due to increasing demographic pressure.

As was the case in most countries around the world, Pacific island nations have resorted to importing new species known for their favourable biological traits, to start aquaculture production. To refer to these introduced species in the present study, we have used the terms "exotic", "non-native" or "introduced" and avoided the use of the term "invasive". It is important to recognize that (a) the impacts, or potential impacts, of most non-native marine species have never been evaluated (e.g., Ruiz et al. 1999, 2011a), and (b) such impacts can vary greatly in space and time. Thus, it is currently not possible with any confidence to divide non-native marine species into those that are invasive and those that are not, based on current impact alone. However, in the absence of data, the precautionary approach would be to assume that most non-native species have the potential to cause harm under some circumstances. Therefore, the use of the term "invasive" is restricted primarily to cases where specific negative effects are perceived or recognized.

According to Carlton (1996), species that occur in a region are considered to fall into one of three categories: native, non-native, or cryptogenic. The latter are species of uncertain origin, reflecting a poor state of knowledge about taxonomic identity and/or biogeographic origin of an organism. A large number of species in a region may be cryptogenic, as is the case with many locations with limited historical data, such as tropical marine ecosystems (Paulay et al. 2002).

Numerous aquatic species have been introduced into the Pacific region for various reasons (both accidentally and deliberately). Some of the main reasons for the deliberate introduction of exotic aquatic species are:

- Recreational fishing (e.g., rainbow trout into PNG).
- Biological control of certain pests (e.g., Tilapia mossambicus into most PICTs).
- Aquaculture (e.g., white-leg shrimp into most PICTs).
- Ornamental/aquarium trade.
- Research purposes (e.g., various species of groupers into Palau).

Additionally, numerous species have been introduced accidentally, through ballast water, biofouling or as hitchhikers accompanying other introduced species.

The introduction of exotic species, including aquatic species, to new environments by human activities, both intentionally and accidentally, has been identified by scientists, environmentalists, governments and industry as a major and increasing concern. Marine bio-invasions, including via vessel-related vectors such as ballast water and hull fouling, have been identified as one of the four greatest threats to global marine bio-diversity and ecosystems, and are a significant threat to coastal economies and even public health.

The potentially serious threats posed by introduced marine pests (IMPs), combined with the extremely high value and significance of coastal and marine resources to Pacific islands peoples, highlights the importance of vigilance regarding future aquatic introductions.

However, when it comes to the aquaculture sector, the contribution of exotic aquatic species has been of vital importance. More than 90% of the aquatic production of the Pacific region, both in volume (metric tons) and in value (USD) comes from exotic species, which were introduced for the development of the aquaculture sector in the region.

It should be emphasized that four of the six main aquaculture species in the Pacific region have been introduced (exotic), by order of production in volume:

- Blue shrimp (*Penaeus stylyrostris*)
- Nile tilapia (*Oreochromis mossambicus*)

- Red cottonnii algae (*Kappaphycus alvarezii*)
- Freshwater prawn (*Macrobrachium rosenbergii*)

In the present paper, we present the cases of marine shrimp, Nile tilapia and red seaweeds, in order to illustrate impacts by exotic species in the Pacific aquaculture sector. The cultivation of these and other exotic species (rainbow trout, common carp, Chinese carps, etc.), is a crucial income generating activities for many countries.

Despite the the risk to the high aquatic biodiversity of PICTs, countries have continued to introduce new species for aquaculture. Some of the main drivers for aquatic species introductions in the region are:

- Commercial/economic drivers:
  - Early entry profits for aquaculture.
  - Commercial demand for aquaculture products to try new markets or replace existing species that have culture or marketing problems.
- Ease of working with many introduced species:
  - Many introduced species used in aquaculture have been the subject of genetic improvement and health programmes.
  - Promotion of new technologies (e.g. Specific Pathogen Free).
- An important driver, uniquely for PICTs, is that, despite the high biodiversity, hardly any of the indigenous species have been domesticated or form the basis for internationally traded aquaculture commodities. The countries themselves possess limited capacity for research and development into domestication programmes.
- Food security and rural development.

Species were introduced in the past with very little precautions at the biosecurity level. However, the current trend in most PICTs, is towards the strengthening of biosecurity legislation and policies in order to deal with animal health related issues, food safety standards and species introductions (export and import standards). Due to the relevance of the fisheries and aquaculture sectors in the region, the aquatic component is relatively strong in most of these regulatory frameworks.

For example, a detailed and complete regional biosecurity strategy for Micronesia has been developed and is currently being implemented. The strategy includes specific components on freshwater and marine species. The strategy is based on previous risk analyses developed for each group of species and for each country of Micronesia, taking into account the main vectors of possible accidental or deliberate non-legal introductions and including the risk of entry of diseases and exotic pathogens associated with the introduced species.

Additionally, the following countries have developed and are beginning to implement national strategies on aquatic biosecurity: PNG, Cook Islands, Solomon Islands, Tonga, Samoa and Fiji. These national strategies aim to standardize protocols for the deliberate introduction of aquatic species, and the measures in place to minimize accidental releases of aquatic species, including exotic aquatic pathogens.

Without any doubts, the region is and will continue to introduce exotic species for further development of the aquaculture sector. This will include, not only new species, but also new/improved breeds, strains and varieties of existing exotic species. For instance, several countries currently farming Nile tilapia, such as Fiji, Vanuatu, Samoa, Solomon Islands and PNG are considering the introduction of an improved strain of Nile tilapia (GIFT – Genetically Improved Farmed Tilapia - tilapia) from Malaysia. In line with new national biosecurity strategies, these introductions will be conducted based on researched and country specific import risk analysis.

Governments of PICTs have the responsibility of assessing benefits versus risks of aquatic species introductions. Management of introduced species must balance both costs and benefits with due consideration for the precautionary approach given at times the paucity of information on the topic.

3. Main aquatic species introduced in the Pacific region for aquaculture

Detailed quantitative studies and documentation of aquatic organisms introduced to Pacific Islands since European contact is for the most part anecdotal, since scientifically based studies and assessments have not been conducted. The introduction of species for aquaculture is only fairly recent with most species imported over the past 50 years. According to Eldredge (1994), these introductions took place when

Figure 2. Seaweed farm in Solomon Islands

Figure 3. Marine shrimp farm in New Caledonia

Figure 4. Nile tilapia farmed in "hapas" in Samoa

emphasis was placed on the development and expansion of terrestrial agriculture and marine and freshwater aquaculture, resulting in a wave of intentional introductions. These introductions were both from countries within the region (e.g, oysters and pearl oysters) and from outside the region (e.g., tilapia, freshwater prawn, marine shrimp, pearl oysters, red seaweed). Eldredge (1994) listed up to 56 species and strains of molluscs, crustacean, fish and seaweed introduced for aquaculture up until the time of his publication. Three separate case studies will later provide more details on the introduction of marine shrimp, tilapia and seaweed. These three commodities have had region wide impact on aquaculture development. Of the remaining species introduced many failed to make any significant contribution to food security and/or livelihood but there are a few commodities that deserve further attention for the positive impact they have had at either regional or country level. This section focuses essentially on farmed species and does not include species introduced for conservation (e.g., *Tridachna gigas*) or sea ranching (e.g., trochus, green snail and sea cucumbers).

Non-native freshwater and marine fish

The introduction of freshwater fish in the Pacific region was originally intended to bolster inland fisheries productivity. While there are other minor species (e.g., grass carp) three of the species introduced for this purpose have now become aquaculture commodities at regional or national level: tilapia (*O. niloticus* and *O. mossambicus*), common carp (*Cyprinus carpio*) and rainbow trout (*Oncorhynchus mykiss*).

Based on these three introduced species PNG is seeing the emergence of a commercial aquaculture sector where stand-alone hatcheries and feed mills supply growers (Pickering, 2011). The commercialisation of aquaculture is not new in the region but previous models were for medium to large scale operations driven by significant government support and private investment (e.g., marine shrimp in New Caledonia and pearl oysters in French Polynesia). The commercialisation of small scale aquaculture seen in PNG, albeit involving small farmers but thousands of them, is however, a first for the Pacific region and it serves as a great example of the socio-economic benefits of introducing species fit for the purpose of improving food security in remote areas. In PNG, common carp makes up the greatest number of fingerlings from hatcheries while GIFT tilapia fingerlings tend to be produced by farmers themselves. The rainbow trout was first introduced in PNG's highlands in 1949 and farming started in Goroka in 1973 (Grubb, 2003). The farm included a hatchery capable of supplying fingerlings to small pond holders. After years of interruption the farm was restarted with assistance from the National Fisheries Authority and the importation of a batch of eyed-eggs from Tasmania, Australia (Pickering, 2011).

It is expected that Fiji and Vanuatu will follow PNG's lead with a more commercial model of aquaculture and private investment in stand-alone hatcheries, growout facilities (small and large scale) and feed and equipment suppliers. For instance in Fiji, the aquaculture of non-native species is progressing positively with the recent hatchery production of grass carp (*Ctenopharyngodon idella*) fingerlings. Grass carp was introduced to Fiji in the 1974 to remediate against the noxious submerged weeds *Hydrilla verticillata* and *Potamogsaton crispus* (Murty and Tui Cavuilati, 1977). Besides its obvious favourable aquaculture traits (i.e., fast growth and low protein diet), grass carp cannot become invasive in this instance as it does not reproduce in the Fiji river systems.

The main finfish marine species introduced for aquaculture in the Pacific region is Barramundi (*Lates calcarifer*) with initial projects having taken place in PNG and Vanuatu. Both operations relied on the importation of fingerlings from Australia and production has now ceased in both countries due to the lack of technical capacity and to the extensive damage caused by cyclone PAM in 2015, in PNG and Vanuatu, respectively.

Non-native crustaceans

Besides the marine shrimp species which are dealt with in a separate case study, the giant freshwater prawn (*Macrobrachium rosenbergii*) has been introduced to several countries and is now being farmed in small scale operations in Fiji, PNG and Vanuatu. Relatively large volumes of 15-20 tonnes per annum were also produced in French Polynesia before it was phased out in the late 1990s to be replaced by marine shrimps (Bermudes, 2018). *M. rosenbergii* was introduced as a preferable option to the native *Macrobrachium lar* because it can be produced in the hatchery and production technology is well developed. While production level of freshwater prawn are still low relative to marine shrimp, the species offers the possibility of small scale farming with locally available feedstuff and as such production volumes are likely to grow in the future with increasing demand and need for locally produced food.

Non-native bivalves

Several bivalves have been introduced to the Pacific region and while most have failed to turned into farming activities there are several cases of viable commercial small and large scale enterprises.

Regarding edible oysters the Pacific oyster (*Crassostrea gigas*) has been introduced to most countries of the region (Eldredge, 1994).

While some remarkable growth rates have been obtained with this species, with product ready to market in less than a year, the reliance on imported seed and the heavy mortality experienced during growout in tropical waters (~80%) make this species unsuitable for farming in the region for most small scale farmers. New Caledonia is the only country in the Pacific to culture *C. gigas* from seed to plate and this is only made possible by the relatively high volumes produced (i.e., one farms supplies the entire market) and the high retail price on the domestic market. Trials in other countries such as Fiji did not prove viable. Angell (1986) reported some *C. gigas* established in the wild in Fiji but despite the repeated mass introduction throughout the region, there is little evidence that it has become established as an invasive species, possibly due to the unsuitability of the environment.

During the late 1970s AQUACOP (French Polynesia's aquaculture development agency) worked on the hatchery production of the green mussel (*Perna viridis*) imported from the Philippines in 1978 (Coeroli et al., 1984; Eldredge, 1994). With the seed produced in the hatchery, recorded trials took place in Tahiti and Samoa.

Perna viridis displayed some excellent growth potential in the Pacific, notably in Samoa (Bell and Albert, 1983) where trials were eventually terminated after stock was lost through successive cyclones. Interestingly, cyclone damage also ended trials in New Caledonia where the species was also introduced and hatchery reared (Munro, 1993; Eldredge, 1994). Beyond those first trials hatchery production stopped in French Polynesia putting an end to the promising results seen in Samoa. *P. viridis* is known as a potentially highly invasive species and can cause serious biofouling problems. There is however no evidence that it has become established in the region despite anecdotal reports of hatchery drains being packed with mussels during production.

The winged pearl oyster (*Pteria penguin*) is one example of an introduced bivalve becoming established in the region. On the island of Vava'u, Tonga, *P. penguin* was introduced from Japan in 1975, 1976, 1977 and 1979. The first evidence of establishment came in 1992 and with it followed the establishment of the Tonga Mabe pearl sector based on natural spat collection (Tanaka, 1990). The industry is continually expanding, counting now a total of 17 farms across Tonga and is being supported with funding and technical support from the Australian Centre for International Agricultural Research which has been pivotal in developing hatchery techniques to sure up the supply juveniles that would otherwise not be sufficient given the small size of the breeding stock in the wild.

The examples highlighted above illustrate the inherent challenges that exist in the region with aquaculture development. Despite all species introduced being mass cultured in their place of origin the transfer to the Pacific is not just a simple matter of translocation of genetics but requires a concurrent and significant investment in capacity building. The promising results seen with *P. viridis* came to nothing when hatchery production ended. The reverse can be seen with *P. penguin* in Tonga where consistent development effort results in a positive outcome leveraging the biological traits of an introduced species to provide opportunities that would otherwise not have existed.

Table 1 provides a summary of the most relevant introductions of aquatic species into Pacific Islands.

Table 1. Summary of aquatic species introductions in the Pacific region by species groups

Species names	Countries
Bivalves	
Giant clams	
Tridacna gigas *Tridacna derasa* *Tridacna squamosa* *Tridacna maxima* *Tridacna crocea* *Tridacna tevoroa* *Tridacna rosewateri* *Hippopus hippopus* *Hippopus porcellanus*	American Samoa, Cook Islands, Federated States of Micronesia, Fiji, Guam, CNMI, RMI, Tuvalu, Samoa, Tonga
Oysters	
Crassostrea belcheri	Tonga
Crassostrea echinata	Fiji, French Polynesia, Guam, New Caledonia
Crassostrea gigas	Fiji, French Polynesia, Guam, New Caledonia, Palau, Tonga, Vanuatu, Samoa
Crassostrea iredalei	Fiji, Tonga
Crassostrea virginica	Fiji, Tonga
Ostrea edulis	Fiji, Tonga
Saccostrea commercialis	Fiji, New Caledonia, Tonga
Saccostrea cucullata tuberculata	Guam
Perna viridis	Cook Islands, Fiji, French Polynesia, New Caledonia, Tonga, Samoa
Pinctada spp.	RMI, Palau, Tonga, Cook Islands, Kiribati, Palau, French Polynesia, Papua New Guinea
Gastropods	
Trochus niloticus	Federated States of Micronesia, CNMI, Guam, Fiji, Kiribati, Cook Islands, French Polynesia, RMI, Tuvalu, Tokelau, Samoa, Vanuatu, Niue
Turbo marmoratus	Papua New Guinea, Vanuatu, Solomon Islands, Cook Islands, Federated States of Micronesia, New Caledonia
Fishes	
Marine fishes	
Poecilia spp.	Guam, French Polynesia, Federated States of Micronesia
Epinephalus spp.	Guam, French Polynesia, Federated States of Micronesia
Lutjanus spp.	Guam, CNMI, French Polynesia, Federated States of Micronesia
Omobranchus elongatus	American Samoa
Freshwater fishes	
Oreochromis mossambicus	Most PICTs
Oreochromis niloticus	Most PICTs
Chinese carps (e.g., common carp, silver carp, big head carp, black carp, grass carp)	Most PICTs
Onchorrynchus mykiss	Papua New Guinea, French Polynesia
Salmo trutta	Papua New Guinea, Fiji
Salvelinus fontinalis	Papua New Guinea
Chano chano	Cook Islands, RMI, Kiribati
Anguilla rostrata	Guam
Puntius selaei	Guam, Palau
Puntius gonionotus	Papua New Guinea, Fiji
Ictalurus punctatus	Guam, French Polynesia
Clarias batrachus	Papua New Guinea, Guam
Gambusia affinis	Papua New Guinea, Fiji Guam, RMI, CNMI, Federated States of Micronesia, American Samoa, Cook Islands, French Polynesia, Samoa, Solomon Islands, Vanuatu

Species names	Countries
Poecilia reticulata	Papua New Guinea, Fiji, Guam, Palau, Cook Islands, French Polynesia, Samoa New Caledonia, Vanuatu
Poecilia mexicana	Fiji, American Samoa, French Polynesia, Samoa
Channa striata	Fiji, Guam, New Caledonia
Lates calcarifer	French Polynesia, Guam
Trichogaster spp.	Papua New Guinea, New Caledonia, Guam
Crustaceans	
Penaeid shrimp	
Metapenaeus ensis *Penaeus aztecus* *Penaeus indicus* *Penaeus japonicas* *Penaeus merguensis* *Penaeus semisulcatus*	New Caledonia, French Polynesia, Fiji, Papua New Guinea
Penaeus monodon	Fiji, French Polynesia, New Caledonia, Guam, CNMI, Solomon Islands American Samoa
Penaeus stylirostris	French Polynesia, New Caledonia, Fiji, Guam
Penaeus vannamei	New Caledonia, French Polynesia, Vanuatu, Fiji, Papua New Guinea, Guam, CNMI
Other crustaceans	
Scylla serrata	Guam, CNMI, Fiji
Macrobrachium rosenbergii	French Polynesia, New Caledonia, Fiji, Papua New Guinea, Vanuatu, Solomon islands, Guam, CNMI, Samoa, American Samoa
Seaweeds	
Kappaphycus alvarezii	Fiji, Kiribati, Solomon Islands, Cook islands, Papua New Guinea, Vanuatu, New Caledonia, French Polynesia, Tonga, Samoa, Federated States of Micronesia, Guam, CNMI, RMI, Tuvalu

4. Case studies on the impact of aquatic exotic species in the Pacific region

Through three case studies (Nile tilapia, marine shrimp and red seaweed cottonni), the present investigation highlights some of the aquaculture successes that have emerged from the introduction of new species in the Pacific region.

Due to the limited record keeping within the aquaculture sector in the Pacific, apart from certain territories and countries, production data in value and volume for the three aforementioned species is predominantly based on personal communications from national officers, compared and crosscheck with FAO official information on fisheries and aquaculture (Fishstat Plus J.).

4.1. Case studies on the impact of aquatic exotic species in the Pacific region: Tilapia fish

Background information

Some Pacific island countries place a high priority on the development of freshwater aquaculture of tilapia in response to pressing needs to produce more fish for food security. This is particularly so in the high-island countries of Melanesia and Polynesia with relatively large and growing human populations, that have sufficient land and surface water resources for pond aquaculture.

To close a widening gap between demand and supply of fish in the Pacific, an additional 100,000 tonnes of fish will be needed annually by 2030 (Bell et al 2009). Coastal fisheries will not produce the fish needed in 16 of 22 PICTs, even with good fisheries management. Climate change threatens to increase the emerging gap between fish needed for food security and the fish available. Two vehicles promise to help fill this gap: allocating more of the Pacific region’s tuna to food security, and development of pond aquaculture.

Tilapia is an introduced fish now widespread in the Pacific region (Eldredge 1994). Nile tilapia (but not Mozambique tilapia) has biological traits that make it the best option for freshwater pond aquaculture in the Pacific, when compared with indigenous candidates like mullet, or milkfish (Sulu et al. 2016).

However any environmental impacts (for example, upon indigenous fish) should be avoided or mitigated. Ways must be found to reconcile tilapia aquaculture development aspirations with protection of biodiversity.

Historical overview of the species' farming in the Pacific

Mozambique tilapia *Oreochromis mossambicus* was introduced into the Pacific in the 1950s (beginning with Fiji Islands and Papua New Guinea in 1954), not for aquaculture, but for intentional stocking to establish new freshwater fisheries (Van Pel 1955). It has established widely in freshwater rivers and lakes, and coastal (brackish water) lakes in most Pacific islands (Eldredge 1994).

"The introduction of tilapia was a disaster on nearly all Pacific islands" is the widely quoted remark by Baird (1976). Often quoted out of context as referring to all tilapias in every Pacific scenario, Baird was in fact alluding to the early onset of sexual maturity which results in over-population and stunting of this fish when raised in small ponds, a biological trait which makes Mozambique tilapia unsuitable for aquaculture.

Baird (1976) did however note the success of tilapia in the establishment of new freshwater fisheries such as in the Sepik region of PNG, where by 1979 an annual Mozambique tilapia catch of around 3000 tonnes was being reported (Kan, 1979). The Sepik tilapia landings have remained in the range of an estimated 1500-4000 tonnes per year ever since and constitute 50% of PNG's freshwater fish catch (Gherkhe et al 2011). Communities throughout Melanesia now value Mozambique tilapia highly as a food fish. In addition to Sepik, Mozambique tilapia fisheries are important to people in Fly River region, Rennell Island, Tikopia Island, the peri-urban area surrounding Honiara, in rivers of Fiji Islands and Vanuatu, and other places.

The particular Mozambique tilapia variety introduced to the Pacific has very poor potential for genetic improvement, because they are derived from 5 fish discovered in Indonesia in 1938 which were subsequently introduced to other parts of South East Asia and Micronesia (Devambez 1964). Awareness about the superior biological traits of Nile tilapia *Oreochromis niloticus*, and continued interest in small pond aquaculture, led to introductions of this species from the 1980s onwards (Eldredge 1994). The domesticated GIFT (Genetically Improved Farmed Tilapia) Nile tilapia, and to a lesser extent the red hybrid between Nile tilapia and Mozambique tilapia, are the varieties upon which successful pond aquaculture in the Pacific are now based.

Though pond aquaculture of tilapia in the Pacific was originally conceived and promoted for food security purposes, in recent years there is an increasing trend toward commercial tilapia aquaculture in places like PNG, Vanuatu and Fiji. Rather than be treated as a sideline activity among a suite of rural livelihood options, investments are now being made in tilapia pond or cage aquaculture as a primary business. This has been made possible by increased demand for fish generally, combined with availability of a domesticated variety of Nile tilapia, increased availability in formulated pellet feeds through either local manufacture or importation from SE Asia, and increased technical capacity in the Pacific to breed and rear tilapia. In order to remain competitive, Pacific tilapia growers will need continued access to further improved and domesticated varieties of tilapia as they become available.

Main producing countries

Papua New Guinea is the leading Pacific country for engagement in tilapia farming, with an estimated 60,000 tilapia farms operating nationwide in 2017 (Jes Sammut, pers. comm.). Many are small, located in remote highland areas, and focused upon subsistence production for household consumption. An increasing number of institutions such as schools and prisons in PNG are adopting tilapia farming in their programs. There is an emerging business-oriented tilapia production sector, currently located primarily in the hydro lakes at Sirinumu and Yonki and based upon floating cage culture techniques.

Fiji has the longest track record in pond production of tilapia, supported by a consistent government program of assistance in fingerling supply, pond construction, and extension services. The number of farmers nationwide at any one time is between 300 and 500, depending upon fingerling availability. Vanuatu, Samoa, Cook Islands, Guam and Saipan also have on-going Nile tilapia farming activity, for example there are 60 tilapia farms in Samoa. Mozambique tilapia occurs in Solomon Islands but not Nile tilapia, however it remains the basis for on-going commercial and subsistence tilapia farming (Cleaseby et al 2014).

Production of tilapia in the Pacific is very difficult to estimate, for several reasons. Firstly, national capacity to collect any kind of fisheries and aquaculture statistics needs strengthening. Secondly, many tilapia farms are located in remote and inaccessible inland areas where farm visits are difficult, and farmers do not themselves keep farm records if their objective is food security. Thirdly, pond production is usually continuous with many partial harvests, rather than pond cycles of total-harvest followed by re-stocking.

For these reasons, no accurate estimate exists for tilapia production in PNG. In Fiji, it is estimated to be in the range of 150-300 tons per year.

Figure 5. Nile tilapia pond in Samoa

Socio-economic impacts

Freshwater fisheries based upon Mozambique tilapia, and upon Nile tilapia for those countries where this species has also been introduced, have contributed greatly to rural and inland nutrition in places like Sepik and Fly rivers in PNG, and in lakeside communities in Rennell and Tikopia islands in Solomon Islands.

In some of these places (such as Rennell), tilapia is the only food fish of any significance (Leqata, 2007). The contributions of freshwater fish species to fisheries production in the Pacific, including those of introduced species like tilapia, are reviewed by Gerhke et al. (2011).

It is widely considered that the socio-economic impacts of small-pond tilapia aquaculture in the Pacific are sufficient to make the activity worthwhile, however this has not been a subject of rigorous academic research due to the paucity of farm data and statistics.

In some cases government subsidies are involved (as in Fiji, with fingerling supply) because government places value upon the nutritional benefits for inland areas where fresh fish is scarce. The socio-economic case for Mozambique tilapia aquaculture in Solomon Islands was investigated by Cleaseby et al (2014) who found that peri-urban households that are cash poor are likely to benefit nutritionally from easier access to tilapia or other freshwater fish. There are many instances in Solomon Islands and elsewhere (such as in Vanuatu and PNG) where community level tilapia farming is self-supporting without subsidy.

Livelihood benefits have historically been over-stated by the promoters of tilapia aquaculture, according to authors such as Gillet (1989). Nevertheless there is now an increasing trend toward investment in tilapia aquaculture at the small-to-medium-enterprise SME level, particularly in PNG, Fiji and Vanuatu. In this regard, the Pacific is tracking the progress of the SE Asian tilapia industry but lags behind it by about 30 years.

Figure 6. Commercial size Nile tilapia in Samoa

Only recently has Pacific aquaculture been assessed from a gender perspective. Draft publications for Gender Analysis of the Aquaculture Sector in Fiji, and in Samoa, (SPC, in prep.) reveal the significant role of Pacific women in the management of aquaculture activities, which is often not recognized and not valued. As is traditional for other rural agricultural practices, tilapia farming in these places has a very pronounced gendered division of labor. Women respondents generally perceive that they do benefit from small-pond tilapia aquaculture. It is providing cash income for women's personal needs and community obligations, often in places where there are no other alternative income sources for women. There are documented instances where tilapia aquaculture activities are having an impact on the empowerment of women with respect to more decision-making opportunities, and are leading to their greater recognition in formal structures within communities.

Small-pond aquaculture of tilapia makes contributions to rural nutrition during post-cyclone recovery and rehabilitation of fisheries-dependent communities in the Pacific. One of the dramatic impacts of Cyclone Winston in Fiji during 2016 was a sharp reduction in the number of times a week communities were eating fresh fish (Chaston Radway et al 2017). For some communities tilapia fish from ponds was the only source of fresh animal protein available in the initial 2-3 month post-cyclonic disaster period and until international relief efforts could be mobilised.

When coastal communities in Fiji who had many of their livelihood assets destroyed or significantly damaged as a result of Cyclone Winston were asked to provide suggestions for potential livelihoods they would be interested in post-cyclone, aquaculture was the main livelihood need identified in the provinces of Cakaudrove, Tailevu and Lomaiviti (Chaston Radway et al. 2017).

Beneficial socio-economic impacts from tilapia aquaculture, long anticipated for the Pacific since at least 1950, have taken time to be delivered due to unsuitable initial choice of species, logistical constraints due to the Pacific's fragmented geographies, and lack of technical capacity. This tide is now turning, due to transfer of know-how and improved domesticated varieties (such as GIFT) from SE Asia. The future effects of climate change in the south west Pacific are predicted to be beneficial for tilapia aquaculture, so this sector will be able to make a useful contribution toward climate change adaptation (Pickering et al. 2011).

Tilapia will play an increasingly prominent role in the delivery of food and livelihoods in the Pacific, in a future where over-fishing, environmental degradation, and the projected impacts of climate change will continue to deplete an already depauperate indigenous freshwater fish fauna.

Environmental and ecological impacts

The case of tilapias as aquatic exotic species in Asia and the Pacific has been reviewed by De Silva et al. (2004). After considering the available literature, De Silva (2004) did not find explicit evidence, or an objective synthesis of information, to show that tilapias have brought about negative ecological impacts including loss of biodiversity in the Asia/Pacific region.

Arthur et al. (2010) quantified the impact of tilapia and carp stocking on native fish communities in freshwater wetlands of the Mekong region in Lao through observational and experimental impact–control studies, and found that stocking of these non-native species was associated with significant increases in total fish biomass, by 180% in the observational study and by 49% in the experiment. Native fish biomass was not affected by stocking of the non-native species. No significant impacts on native fish species richness, diversity indices, species composition or feeding guild composition were detected, except for moderately negative effects on Simpson diversity and equitability in the observational study.

In considering both Asia and the Pacific, De Silva et al. (2004) point out that the Pacific represents a different zoogeographic zone, with a different freshwater fish fauna that is less diverse than Asia and of marine ancestry. Spawning is often estuarine and larval stages are marine, so life cycles involve migrations. Connectivity between terrestrial, estuarine and marine habitats is vitally important (Jenkins et al. 2010). The majority of Pacific freshwater species are visual predators that require high water clarity to hunt, and high oxygen levels.

The possibility of environmental consequences in the Pacific, including effects upon indigenous fish stocks, from introduced species such as tilapia has received much less scientific attention than in Asia and thus it can be more controversial (Gerhke et al 2011). Concerns expressed about tilapia as an introduced exotic species in the Pacific mainly relate to knowledge gaps, and application of the precautionary principle.

Mozambique tilapia is listed among the "100 worst" of the Global Invasive Species Database (http://www.iucngisd.org/gisd/species.php?sc=131, accessed 3/3/18), mainly on the basis of being able to easily establish and be difficult to eradicate. Possible impacts are speculated-upon, but without evidence of demonstrable causal links.

Invasive alien species are defined as "plants, animals, pathogens and other organisms that are non-native to an ecosystem, and which may cause economic or environmental harm or adversely affect human health. In particular, they impact adversely upon biodiversity, including decline or elimination of native species - through competition, predation, or transmission of pathogens - and the disruption of local ecosystems and ecosystem functions" (https://www.cbd.int/idb/2009/about/what/, accessed 3/3/18). Whether tilapias in the Pacific fall in to this definition has not been clearly demonstrated. Any concerns or perceptions about tilapia impacts are therefore based upon supposition that they might.

To establish an appropriate level of concern one way or another, it is necessary to consider how the presence of tilapia in the Pacific for the last 60 years fits within the whole suite of threats to Pacific indigenous freshwater fishes. Gerhke et al. (2011) and Maclean and Jones (1995) list the threats to their production and biodiversity as possibly stemming from (i) habitat loss and degradation, (ii) over-fishing, (iii) spread of alien species, (iv) pollution, and (v) climate change.

The alteration of cool clear-running shaded streams to warm sunlit turbid environments with higher primary productivity, caused by deforestation, siltation and eutrophication, can be particularly effective in converting indigenous-fish habitats into tilapia habitats.

Jenkins et al. (2010) surveyed streams in Fiji Islands and reported that, on average, stream networks with established *Oreochromis* spp. populations have 11 fewer species of native fish than do intact systems. While the analysis presented in their paper did make mention of concurrent factors such as catchment land-clearing, in the international press coverage following its publication the reported biodiversity difference was attributed to predation by tilapia (see, for example, http://fijisun.com.fj/2010/01/15/tilapia-feeds-on-fijis-native-fish/ accessed 3/3/18). This led to an online discourse about the difference in science between correlation and causation (http://scienceblogs.com/observations/2010/04/06/tilapia-and-fijis-fish-revisit/, accessed 3/3/18).

The recent example of establishment by tilapia in the Middle Fly region of PNG several years after loss of flood plain forest cover resulted in disappearance of indigenous fish (Masuda et al. 2011) provides an alternative explanation for the results of Jenkins et al. (2010). The type of habitat most suitable for establishment of tilapia is habitat altered to the point where indigenous fish species have already departed. In such cases tilapia can be found at the scene of a crime, but is not necessarily the criminal.

De Silva et al. (2004) relates the case of near extinction of an endemic goby *Mistichthyes luzonensis* in Lake Buhi in Phillipines, which had similarly been attributed to predation by tilapia. On further consideration it was concluded that its decline in numbers were due to a number of factors, of which environmental degradation was the major one and the presence of tilapia was the least. In the time since the environmental issues in Lake Buhi have been addressed, the species is recovering.

Knowledge gaps

There is extremely limited information generally about freshwater and estuarine fisheries resources in the Pacific. This makes it difficult to manage them or to estimate the likely impacts of any of the various threats to indigenous fishes.

Specifically there have been no studies in the Pacific aimed at teasing out the issue of tilapia, as a possible contributor toward impacts on indigenous fishes, from other threats like land clearance, mining, pollution, and loss of connectivity between life cycle habitats. Such research, to prove or disprove causal links between tilapia and impacts on indigenous fishes, will be useful to help resolve any controversies surrounding tilapia in the Pacific (Pickering, 2010).

Possible aspects of interactions between tilapia and indigenous fish fauna that should be researched to inform policy about tilapia introductions include; competition with indigenous fish; predation upon indigenous fish and invertebrates; ecosystem disruption, and; introgression of genes from improved varieties of tilapia into feral populations.

Where gaps in knowledge exist that create uncertainties for decision-makers, these should be addressed through targeted scientific research. In the interim, policies should be adopted that take into account the Precautionary Principle.

Public perceptions

De Silva (2004) comments that, because of a lack of quantitative information and objective studies on the effects of tilapia, it is potentially a more controversial subject in the Pacific than in SE Asia. Even so, there is now a 60-year history of tilapia being present in the Pacific and general perceptions among the populace have overall been positive.

This is particularly so for tilapia introduced to the large lake and river systems of Melanesia. Lakeside communities in Rennell Island recently raised concerns about reduction in catches of Mozambique tilapia from Lake Tegano, upon which they are utterly dependent for fresh fish (Leqata, 2007).

The relatively recent appearance of good-sized Nile tilapia in the Fly river system in 2010 has been especially welcomed by local communities, because ecosystem changes caused by the OK Tedi mine had already caused severe declines in catches of indigenous food fishes in the years preceding the appearance of tilapia (Masuda et al. 2011). Tilapia is seen as a major food-security and commercial opportunity by these communities, who are looking ahead to the period beyond the closure of the mine and cessation of royalties to traditional landowners.

In times past, there have been reports of calls for eradication of tilapia from Nauru and Kiribati because it is viewed as a pest (Eldredge 1994), however this needs to be interpreted in with caution. Such calls arose mainly by perceptions that Mozambique tilapia is not a particularly useful fish when stocked into small water bodies such as those available on atolls, due to its propensity for over-crowding and stunting. When good-sized Mozambique tilapia are found in these places, they are appreciated. People in both these countries remain interested in introduction of Nile tilapia, viewing this as a way to overcome the stunting issue experienced with Mozambique tilapia.

While disappointment has at times been expressed in the ability of tilapia to deliver food security benefits through small-pond aquaculture at household level (see for example, Gillet 1989) government support in several Pacific countries has continued from the 1950s to the present day. The Aquaculture Development Plans and other stakeholder-participatory national planning instruments of PNG, Solomon Islands, Vanuatu, Fiji, Tonga, Samoa and Cook Islands all list tilapia aquaculture as a priority area for development.

Expectations within communities vary from place to place about the benefits and costs (mainly pond construction costs) of small ponds for tilapia raised with on-farm feeds. In Guadalcanal and Malaita islands in Solomon Islands, many villagers are happy to wait for up to one year to harvest 150g-sized Mozambique tilapia and they regard this as a good result. In Samoa, there is general satisfaction with back-yard cement tank systems for rearing Nile tilapia, combined with curiosity to learn how such tanks can be managed to give even better results. The existence of an estimated 60,000 such tilapia farms in PNG attests to the popularity of the household tilapia pond concept.

A recent trend is the emergence of tilapia farms as livelihood options and businesses in their own right, rather than as sideline activities. PNG, Fiji and Vanuatu are the region’s leaders in commercialisation of tilapia aquaculture. In this sense, the Pacific is following a similar development path as many SE Asian countries did thirty years ago. Many of the lessons of Asian tilapia farming are applicable in the Pacific.

The Pacific faces a future where the two drivers of population growth and climate change will force hard choices to be made, in which risks of declines in biodiversity will need to be balanced against risks of famines for human populations. The increased utilization of tilapia, and further introduction of improved varieties for aquaculture, is a choice that will need to be made. In the face of concern about impacts upon biodiversity, a process is needed to address this issue in a coherent manner.

Such a process could include the following elements:

- socio-economic assessment of the need for, and viability of, tilapia aquaculture in the Pacific on a country by country and province by province basis, before any decision is taken by policy makers to promote or support it;
- strengthen national capacity to manage aquatic-species quarantine protocols, and to carry out import risk assessment for any proposed new domesticated varieties of tilapia, and;
- adopt zoning approaches to aquaculture planning that identify any tilapia-free areas of high conservation value (for example, Samoa's montane lakes), and put in place measures to protect them.

4.2. Case studies on the impact of aquatic exotic species in the Pacific region: marine shrimp

Introduction of aquaculture species in the Pacific region: Case study of marine shrimp.

Introduction

The story of marine shrimp aquaculture in the Pacific region is a varied one from the countries that have never attempted farming the commodity to those that have been producing for the past 35 years. While all countries and territories of the region possess some of the critical prerequisite for shrimp aquaculture (i.e., favourably warm waters of suitable quality and relative freedom from major diseases), only few places such as Hawaii, New Caledonia, Papua New Guinea, Fiji and Vanuatu possess sufficient and suitable sites for the establishment of large-scale traditional pond based farms. Despite the lack of physical space for large-scale farming, some countries such as Guam, CNMI and French Polynesia have introduced shrimp for farming with some success. In many places, shrimp species were introduced despite the presence of endemic species with the potential for farming. This was the case in New Caledonia, PNG and Vanuatu where *P. monodon* and *F. merguiensis* are endemic (Patrois, 2011; Pickering and Forbes, 2002). Therefore and despite the risk of introducing diseases that would seriously compromise the profitability of marine shrimp farming, government authorities still went ahead with the importation of live shrimp largely due to the immediate performance and gains obtained with domesticated strains (Coatanea, 1978).

This case study will summarise past introduction attempts, review the different models/approaches used for establishing shrimp aquaculture in the region, the quantifiable impacts (environmental and socio economic) as well as knowledge gaps for continued sustainable development.

History of marine shrimp introduction in the Pacific

In understanding the impact of the introduction of marine shrimp in the Pacific region, the extensive compilation of aquatic species introduced in the Pacific region by Eldredge (1994) provides a sound starting point to work through the history of shrimp aquaculture development from start to current status. Table 1 lists all species introduced by country in the 1970s and 1980s. All up, 11 countries and territories introduced as many as 13 species of marine shrimps. Out of these 11 countries, only New Caledonia, French Polynesia, Fiji, CNMI, Vanuatu and Guam still have active commercial farms supplying domestic and export markets (i.e., New Caledonia).

French Polynesia introduced 13 species for aquaculture evaluation purposes between 1973 and 1988 (Bermudes, 2018). Not only were there many species introduced but they were imported several times and from many countries around the world. Up to 26 introductions have been accounted for across the different species tested and all from within the region (e.g., New Caledonia) or major producing countries in South-East Asia, North, Central and South America, and Australia. Some of the species introduced were subsequently sent from French Polynesia to other Pacific island countries such as Fiji (*P. indicus*, *P. monodon* and *P. merguiensis*) (Eldredge, 1994). Remarkably though, despite these numerous introductions in French Polynesia, only *P. stylirostris* remains as a farmed species after farming trials of *P. monodon* in 2001, *P. vannamei* in 2004 and *F. indicus* in 2004 (Bermudes, 2018).

Table 2. Listing of the species known to have been introduced at least once in Pacific island countries (adapted from Eldredge, 1994; Patrois, 2011 and Bermudes, 2018)

Country	Species of marine shrimp introduced
American Samoa	*Penaeus monodon*
CNMI	*Penaeus vannamei*
Fiji	*Penaeus indicus, Penaeus japonicus, Penaeus merguiensis, Penaeus monodon, Penaeus vannamei*
French Polynesia	*Farfantepenaeus aztecus, Fenneropenaeus indicus, Fenneropenaeus orientalis or Fenneropenaeus chinensis, Litopenaeus schmitti, Metapenaeus ensis, Melicertus plebejus, Penaeus aztecus, Penaeus esculentus, Penaeus japonicus, Penaeus merguiensis, Penaeus semisulcatus, Penaeus stylirostris, Penaeus vannamei*
Guam	*Penaeus monodon, Penaeus stylirostris, Penaeus vannamei*
Hawaii	*Penaeus chinensis, Penaeus indicus, Penaeus japonicus, Penaeus monodon, Penaeus stylirostris, Penaeus vannamei*
New Caledonia	*Metapenaeus ensis, Penaeus aztecus, Penaeus japonicus, Penaeus merguiensis, Penaeus monodon, Penaeus stylirostris, Penaeus vannamei*
Solomon Island	*Penaeus monodon*
Vanuatu	*Penaeus vannamei*
Western Samoa	*Penaeus monodon*

Figure 7. Shrimp pond in Fiji

Figure 8. *Penaeus vannamei* specimens introduced from Thailand to Fiji in the year 2012

Review of models of development: Government vs private investment

The start-up of any aquaculture sector can be driven by government, private investors or both in partnership (i.e., PPP). The largest public investments seen in the introduction of marine shrimp and subsequent development has been in French territories where governments (central and territorial to start with) poured large amount of public funds for the establishment of research and development programmes and in the establishment of hatcheries for the supply of post larvae and the provision of technical capacity building for private operators willing to invest.

In the case of French Polynesia, the supply of post larvae to farmers is still largely subsidised by the territorial government. The PPP models of New Caledonia and French Polynesia have resulted in sectors that have been producing shrimp continuously for 35 years (Patrois, 2011). In the case of New Caledonia and despite production being small by world standards, marine shrimp is the second export commodity behind nickel. Importantly, the ongoing public investment in those countries means that the sector continues to progress as is discussed later.

Figure 9. Shrimp farm in New Caledonia

The other side of the PPP which made those models so successful in New Caledonia and French Polynesia is the confidence generated on the private investor side with several business minded operators prepared to invest long term in shrimp farming. Recent, current and planned initiatives by government agencies in New Caledonia and French Polynesia include:

1. Farming innovation in French Polynesia where the governmental branch in charge of aquaculture (Direction des Ressources Marines et Minieres) has developed and facilitated private investment in shrimp cage culture in the lagoon. Pilote scale trials for shrimp cage culture in Tahiti have produced promising yields of 19kg per m^2 of cage per annum with FCRs from 3 g to harvest of 1.6 to 1.8.
2. Increased biosecurity limiting the importation of shrimp product and therefore limiting competition from imported shrimp. While somewhat protectionist, this type of strategy has the benefit of generating investors' confidence in securing the domestic market and greatly reducing the biosecurity risk inherent to aquaculture activities and shrimp farming in particular (Bermudes, 2018).

3. Selective breeding of *P. stylirostris* to improve overall performance in both French Polynesia and New Caledonia with, in the later, a focus on developing lines resistant to *Vibrio penaecidae* and *V. nigripulchritudo* which have significantly reduced farm output and profitability since the early 1990's (Patrois, 2011).
4. Increase hatchery production capacity in New Caledonia by solving some of the recurrent hatchery inconsistencies that have plagued the sector over recent years and in French Polynesia by increasing hatchery capacity to meet demand from increasing number of farmers, in particular those investing in cage farming.
5. Polyculture or rotational culture trials with fish and sandfish in New Caledonia to raise farm productivity and in the case of sandfish to determine the benefits of using sea cucumber as a means of pond bottom remediation on crop rotation basis (i.e., shrimp-sandfish-shrimp-etc.).

At the other end of the spectrum are the countries where marine shrimp farming from introduced species was largely driven by private investors with some but inconsistent support from government authorities. This was the case in Vanuatu and Guam. Shrimp farming still occurs in those countries but progress is slow in resolving some of the main constraints to expansion, namely:

1. Competition from imported products. Vanuatu is currently developing new import regulation to improve national aquatic biosecurity and this should limit the entry of imported products that are known vectors of crippling shrimp diseases as was recently the case with the white spot virus in Australia.
2. Supply of post-larvae being partly provided by the Guam Aquaculture Development and Training Centre (GADTC), the shortfall being sourced from hatcheries in Thailand and Taiwan with the biosecurity risk this entails.
3. Stringent environmental regulation as is the case in Guam (Brown et al., 2010, cited by Patrois, 2011) where private developers are constrained by a suit of environmental compliance requirements including a ban on digging ponds that could hinder de development of the sector while at the same time force innovation and in any case ensure minimal environmental impact (Patrois, 2011).

Figure 10. Shrimp farm in Vanuatu

In between continued and inconsistent government supported models, we find examples in PNG and CNMI where private investors where supported by government authorities in their initial setup but where faced with internal capacity limitations as commercial development progressed. These limitations are:

1. Production cost: the cost of production in the Pacific region is often high due to the need to import feed and seed. Even if hatcheries are established, the small scale of their production translate in high post-larvae production costs which are passed down to the farmers and eventually the consumer (unless government subsidies and assistance is in place);

2. Insufficient access to resources (e.g., land) and inputs (e.g., post-larvae, quality feed). In PNG the lack of captive broodstock and the need to source wild caught broodstock resulted in poor hatchery production output which was insufficient to supply the farm (Patrois, 2011).
3. Lack of technical assistance and or capacity, which in the case of PNG resulted in a farm that was poorly conceptualised in the local context (Whitford and James, 2015);
4. Insufficient capital investment due to a lack of support and incentive for investors. The lack of technical capacity on the ground and the lack of qualified and experienced personnel (as well as all above limitations) add to the risk inherent to aquaculture operations and become a serious deterrent to any potential investors. Further to this, there is at times a clear lack of commitment to overcome some of the limitations or to invest in properly conceptualised operations in the first place (possibly due to insufficient expertise or misinformation) as was the case in PNG (Whitford and James, 2015).

The environmental impact of shrimp farming in the Pacific region

There are three major environmental concerns with the introduction of new species. The first two of those concerns are related to biosecurity risk with the potential establishment of the new species in the natural environment and with the increased likelihood of introducing pathogens capable of spreading to other species or phyla such as the white spot virus which is infectious in most crustaceans. The third and last concern is associated with the establishment and production of a new farming sector.

Given the scale of shrimp farming in the Pacific region the direct environmental impact remains negligible. Most countries have some level of environmental control measures in place such as environmental impact statements or assessments depending on the size of the proposed farm (Patrois, 2011). In New Caledonia, with the largest production in the region, farms can only be established behind the mangrove belt in zones normally flooded during high tide and not useable for agriculture (Galinie, 1992). By using this approach, aerial surveys have revealed that only 5ha of mangrove have been lost for 800ha of ponds established (Patrois, 2011). New Caledonia imposes a guide of best practice for shrimp farming as part of accreditation requirements for export. To minimise environmental impact the guide of best practice requires, for example, a maximum stocking densities of 3.5T per hectare. Despite these guidelines several studies have found low to moderate impact in the vicinity of farm outlets, but these results are inconsistent and mostly related to farm effluent outlet design which can be addressed (Virly, 2005; Della Patrona, 2012). Guam is another country with strict and enforced regulation to control and regulate new development, including zoning, effluent control and a ban on digging ponds amongst a host of other rules (Brown et al., 2010, cited by Patrois, 2011).

Fiji accounts for the only known and reported case of an introduced marine shrimp species (i.e., *F. merguiensis*) becoming established in the environment of the importing PICT (Choy, 1983). Despite the many introductions in places such as French Polynesia and New Caledonia, there is no reported evidence that exotic shrimp species have become established in those places. This is possibly simply due to the nature of any framing systems which aim to minimise loss of stock through escape resulting in extremely low probabilities of mating encounter between escapees in the wild. This is greatly helped by shrimp farming being a land based activity.

The shrimp cage development in French Polynesia will be interesting to follow from that respect given that the likelihood of mass escapes in the lagoon is much greater with this type of farming.

By far the greatest biosecurity threat with the importation of live shrimp is with potentially associated pathogens. There have been for instance several reported cases of the infectious hypodermal and hematopoietic necrosis virus (IHHNV) coming with imported stock of *P. stylirostris* in CNMI, French Polynesia, Guam and New Caledonia (Patrois, 2011). *P. stylirostris* being naturally resistant to IHHNV, there has not been significant and long term reported impact on shrimp farming activities. French Polynesia and New Caledonia are now free of IHHNV (Anonymous, 2016; Bermudes, 2018) and the Guam Aquaculture Development and Training Center now produces Specific Pathogen Free (SPF) shrimp post-larvae and broodstock (https://cnas-re.uog.edu/expertise/aquaculture).

A comprehensive screening of *P. monodon* stock in Fiji was carried by Waqairatu and Pickering (2009). While the study revealed the presence of a host of pathogens, it concluded that only Mourilyan Virus and Gill Associated Virus likely originated from Australia while other pathogens may have been naturally present in Fiji shrimps.

While the impact of introduction and establishment of shrimp pathogens have had no reported and significant impact on endemic and cultured shrimps in the Pacific, all countries have or are now considering stronger biosecurity measures and/or the importation and production of SPF stock which is a clear departure from the initial efforts into shrimp aquaculture in the region.

The socio-economic impact of shrimp farming in the Pacific region

Overall shrimp farming has had a positive socio-economic impact in the region with improved food security, the creation of jobs and technical capacity in aquaculture production.

From a food security perspective the volume produced remain small relative to demand and while production is consumed domestically it does not target local markets but tends to be niched as an upmarket commodity for the restaurant and tourism trade. There are some exception to this with one farm in French Polynesia selling its entire production locally and in New Caledonia where local fresh shrimps are found in markets and supermarkets. The produce is often unprocessed, with the majority being sold fresh or frozen whole. The proximity of farms to market makes for a high quality product. The absence of major diseases means that antibiotics are not used beyond the hatchery. High quality, low volumes and high production costs result however in a high retail price and shrimps produced and sold in the Pacific are not an affordable mass consumption commodity from a food security perspective.

Since its peak of 2,600 T in 1990 (Galinie, 1992), production in New Caledonia has been inconsistent (Table 2) being severely hampered by a combination of vibriosis during growout and a shortage of post-larvae. It is expected that the research currently underway to address those issues will allow production to grow again in the coming years. French Polynesia is showing an upward production trend (Table 2)to meet the estimated demand of around 500T of fresh shrimp per annum (Bermudes, 2018). Volumes produced in Fiji, Guam and Vanuatu are poorly documented and only in the order of 10-30 metric tonnes per year. Production in Fiji is expected to increase to meet a growing domestic market and the expansion is supported by government authorities. Production in CNMI and PNG have ceased in 2015 with the only farms in those countries closing due to typhoon damage and lack of profitability, respectively.

Figure 11. Shrimp cage in French Polynesia

Table 3. Annual marine shrimp production volumes (metric tonnes) in French Polynesia and New Caledonia

Country/Year	'07-08	'08-09	'09-10	'10-11	'11-12	'12-13	'13-14	'14-15	'15-16	'16-17
French Polynesia	44	39	39	54	71	79	89	93	103	120
New Caledonia	2047	1853	1149	1477	1640	1555	1672	1252	1587	1636

In some countries and territories such as New Caledonia and French Polynesia shrimp farming has been the leading aquaculture development commodity with much capacity developed throughout the entire production chain from R&D, hatchery, grow out, feed production, processing and export. This in itself creates a sound technical and supply chain platform for other aquaculture development as is being seen in New Caledonia with the development of sea cucumber aquaculture.

Although uneven in its development across countries, the presence of leaders also represents significant opportunities for other countries in terms of technology transfer, supply of SPF broodstock and post-larvae (e.g., from Hawaii and Guam).

Knowledge and capacity gaps

The overall gap between the current production status and reaching full potential resides largely in being able to increase production in the challenging context of small island nations. Given that the technology for shrimp farming already exists, the main challenge is in being able to transfer and adapt this technology with long-term sustainability and growth in mind.

Considering the constraints highlighted earlier, the knowledge and capacity gaps can therefore be summarised into two main objectives:

1. The increase in hatchery output to meet farm demand and ultimately market needs;
2. The development of national or regional shrimp supply chain systems (including post-larvae, feed, production and distribution) using a technology that is profitable and adapted to the context of each country and is able to meet domestic and even local market demand by offering an affordable and competitive product.

This last objective will ensure that shrimp farming not only generates economic opportunities for Pacific island nations and territories but that it also plays a more significant role in improving food security.

4.3. Case studies on the impact of aquatic exotic species in the Pacific region: seaweeds

Sources of information

This case study is focused on the importance of farming exotic species of algae in the Pacific Region. Information provided in the case study is based on the following sources of information:

- Published and unpublished literature on this subject;
- Internal evaluations carried out by the Pacific Community aquaculture section (SPC) between 2010 and 2017;
- FAO official fisheries and aquaculture statistics (Fishstat plus J) to validate some of the personal communications; and
- "Unofficial" information provided by officials and managers in charge of growing algae from the main producing countries in the region, as personal comments. Country information has been facilitated by the following government officers and managers:

Solomon Islands
Mr Sylvester Diake aquaculture officer, from the Solomon Islands.

Samoa
Mr Unity Roebeck aquaculture officer, from Samoa.

Manager of the coastal fishing and aquaculture division of Samoa, Ms Sapeti Tiiti.

Tonga
Fisheries and Aquaculture Officer Mr Poasi Fale, from Tonga.

Federated States of Micronesia
Aquaculture Officer of the Federated States of Micronesia, Mr Mathias David.

Kiribati
Manager of the aquaculture division of Kiribati, Mr Karibanang Tamuera.

Papua New Guinea
Manager of the aquaculture division of Papua New Guinea, Mr Jacob Wani.

Fiji
Manager of the aquaculture division of Fiji, Mr Shalendra Singh.

Introduction

Kappaphycus alvarezii, the elkhorn sea moss, is a species of red algae. It is one of the most important commercial sources of carrageenan, a family of gel-forming, viscosifying polysaccharides. The species is distributed in the waters of East Africa, Indonesia, Malaysia, Hainan Island and the Philippines.

Farming of the red seaweed species *Kappaphycus alvarezii* started around the 1960s, when an American seaweed processing company transferred its procurement of raw materials for the production of carrageenan from Indonesia to the Philippines. During its initial operations, the company sourced its supply of raw materials by collecting the seaweeds from the wild (reef areas in Central Visayas province). Because of the uncontrolled gathering of natural stocks of various species of red seaweed, natural resources were almost depleted in the Philippines by the end of the decade.

The short supply of dried seaweeds for processing triggered research and development work on the culture of these species, the survey and assessment of coastal areas with potential for seaweed farming, and an inventory of the local varieties of these species for comparative growth studies and assessment of the quality of their colloidal products. Based on the results of the aforementioned studies, the first commercial farm for *Kappaphycus* was established in Tapaan Island, Philippines in 1972.

Major producers of this read algae include Indonesia, the Philippines and China, followed by other countries such as including Tanzania and Malaysia.

Seaweed farming is a major livelihood among people living in coastal areas of the aforementioned countries. Farming of seaweeds, as a livelihood activity, is most suited for families living in small islands and in coastal areas because it requires less inputs and cost of production is relatively low. Aside from the seaweed plantlets, ropes and tying materials that are used during the start of seaweed planting, they do not require additional inputs since they only need the nutrients from the seawater and the sunlight to grow. Furthermore, the production cycle of red seaweeds is relatively short, as they can be harvested after 45 days of culture.

Historical overview of seaweed farming in the Pacific

Successful commercial production of seaweed in the four main producing countries of the region (Solomon Islands, Fiji, Kiribati and Papua New Guinea) is currently based on *Kappaphycus alvarezii*, only.

Kappaphycus alvarezii farming has been heavily promoted in the Pacific region for several reasons: requires a low level of technology and investment; does not require high-tech postharvest processing; typically compatible with traditional fishing and other nearshore subsistence activities; potential source of income and employment in rural areas that have few other income-generating opportunities; and, an activity that can provide income for women.

South (1993) reviewed the farming of *Kappaphycus* in the Pacific Islands up until the early 1990s, and reviews since then have included those of Ask (2003), Ask et al. (2003b), Luxton and Luxton (1999), Luxton (2003), South (1993) and South and Pickering (2006).

Regarding other seaweed species that have been or are being tested within the region, it should be mentioned that the brown seaweed *Cladosiphon* sp., which is known to occur naturally in Tonga and New Caledonia, was cultured quite successfully in Tonga for many years, but farming ceased in 2007 due to market difficulties. Other edible species, such as *Caulerpa* sp., *Codium* sp. and *Gracilaria* sp. are currently being grown in several Pacific Island countries in very low volumes (we could say almost anecdotally in most cases) or as part of research and development programmes.

Sea grape (also known as sea caviar), *Caulerpa racemosa*, has been cultured in Samoa and French Polynesia since 2011 with promising results in terms of growth and survival rate. We must report that the production of this species in Samoa has increased and has improved markedly since 2012, thanks to the technical support provided by several regional institutions and donors. There are currently around four coastal communities on the island of Upolu, involved in the cultivation of caulerpa. This algae is intended for local consumption, since the Samoans (like many other inhabitants of Polynesia) consider it a product of high organoleptic value.

Figure 12. Farming *Caulerpa racemosa* in Samoa

Some of the most common opportunities attributed to seaweed farming in the Pacific region are:

- Simple cultivation technique;
- High export market opportunities;
- High employment involved;
- Relatively low capital investment;
- Short cultivation period; and
- Various refined products.

However, there are also important constraints and challenges associated with this farming activity, identified by seaweed farmers:

- Slow growth rate (stunted);
- Susceptible to pests and diseases;
- Biofouling;
- Not resistant to environmental stressor;
- No standard procedure of seed production; and
- Planting season.

Although Pacific Island countries and territories provide a wide range of habitats that are suitable for seaweed farming, there are a numbers of limitations inherent to the region:

- Isolation;
- Distance from markets;
- Small volume of production;

- Vulnerability to world price fluctuations;
- Socio-economic issues; and
- Limited skills and capacities regarding seaweed culture.

However, seaweed production in PICTs continues to be a significant source of income in isolated coastal areas. There are national development plans in place to expand seaweed production to new countries in the forthcoming years (e.g., Republic of Marshall Islands, Federated States of Micronesia, Tonga, Samoa), as well as to scale it production in the top-4 producing countries.

Current seaweed varieties

All cultured stocks of *Kappaphycus* come from outside the region because this seaweed does not naturally occur there, and all *K. alvarezii* strains currently cultivated in the Pacific Islands region were introduced from Southeast Asia during the 80's (i.e. Indonesia, Malaysia and the Philippines).

Nowadays, the variety "tambalang" is the most cultivated. Because of its thick thalli and heavy weight, this variety can take three to five days to sundry, which can be problematic in areas with high rainfall. For this reason, "sacol" (a variety of the species *K. striatum*) was introduced into Fiji during the 1990s. The thalli of the sacol variety are much thinner and less heavy than those of tambalang, so they can be dried faster, sometimes within 24 hours. This species is cultivated on a small scale in some areas of Fiji where rainfall is extremely high.

The Pacific region has also been looking in the past 5 years into sourcing high performing strains developed in Asian countries that are better adapted to the local context.

A new variety of *K. alvarezii*, "maumere", has been introduced into the region from Indonesia. This improved variety was introduced into Fiji in order to implement a set of trials aimed at comparing the performance of the improved maumere variety with the tambalang variety. The tambalang variety, which is farmed in Fiji, has low performance levels (e.g., limited growth and survival rates, lack of resistance to most common diseases, and limited adaptation to environmental fluctuations).

This decreased production may be due to various factors mostly related to the lack of structured selective programmes, poor management strategies, and the inappropriate selection of farming sites.

Varieties that are better adapted to local growing conditions have also been sought. Most of the seaweed cultured in the Pacific is carried out in on-line farming systems, very close to the coastline (what is called the "off-bottom system"). Floating production systems have hardly been developed, due to the lack of technical and financial capacities of the producers.

Being grown in shallow water, near the coast, means that the cultivated seaweed is highly exposed to changes in water quality parameters (salinity, temperature, oxygen, suspended matter, sediments, etc.). For this reason, the major Pacific seaweed producing countries have acquired improved varieties of algae that are better adapted to shallow farming sites.

Some of the most notable exchanges of genetic material since 2012 have been:

- Introduction of improved varieties of red algae K. alvarezii: "tambalang" and "maumere" from Indonesia (Lombok) to Fiji, FSM, Tonga and Kiribati.
- Introduction of the variety "tambalang" from Malaysia (Penang) to PNG.
- Introduction of the "maumere" variety from Indonesia (Lombok) to the Solomon Islands

Farming strategies

Three principal farming methods have been tried in the Pacific Islands region: 1) off-bottom (fixed monofilament lines between posts driven into the substratum); 2) floating rafts (bamboo floating structure); and 3) floating long-lines (rope-made floating structure). Commercial cultivation in Fiji, Kiribati, PNG and Solomon Islands consists almost entirely of off-bottom farming.

Figure 13. Off-bottom farming system in PNG

PNG and Solomon Islands have used the floating longline method during the past two years with very promising results regarding growth and survival rates (Jacob Wani and Sylvester Diake, pers. comm.). Seaweed farmers in Kiribati have used net cages for nursery or seed stock farms to protect plants from fish grazing.

The region does not have any processing plant, therefore, all the product is being exported as dry product. This is one of the major limitations for scaling up the activity within countries, because market prices are very variable and sometimes very low. The low price is compounded by the cost of shipping from isolated locations and with a product that is bulky and high volume.

The region is also focusing on current and emerging developments on seaweed processing and on improving quality right during harvest. These innovative approaches will likely contribute to increased quality and optimize the efficiency of the seaweed sector within the region.

Figure 14. Floating farming system in PNG

Production data

Kappaphycus alvarezii, which is a source of the hydrocolloid carrageenan, has been farmed in the Pacific for more than 20 years, although yields have fluctuated for a variety of reasons.

Kiribati has had the most consistent results, with production at times exceeding 1000 tonnes (t) per year of dried commodity (production data in 2000 and 2001), but has also suffered from losses due to strong winds and rising seawater temperatures. Production in Kiribati has also declined due to the rise in the subsidy of copra which guarantees higher economic return than seaweed farming.

Production in Fiji has fluctuated in the past 10 years, mainly due to the effects of cyclones, political changes, and competition for labour from other commodities such as copra and beche-de-mer. Yields in Fiji have varied from zero to more than 500 t (dry) per year.

The seaweed industry in Solomon Islands has been growing slowly but consistently over the last nine years and it is currently the first seaweed producer country within the Pacific region, with around 1,800 t (dry) reported in 2017.

Table 4. Estimated production in volume (metric tonnes) of dry *K. alvarezii* in the Pacific

Country/Year	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17
Fiji	0	0	0	450	450	1190	650	660	440	560	580	560	470	370	380	320	320
Kiribati	1190	660	467	408	452	619	101	108	216	475	429	636	670	670	645	640	640
Solomon Islands	0	0	0	75	130	100	95	100	200	250	700	1300	1700	1650	1700	1800	1800
PNG	0	0	0	0	0	0	0	0	0	10	25	140	250	350	350	500	500
Total	1190	660	467	933	1032	1909	846	868	856	1295	1734	2636	3090	3040	3075	3260	3260

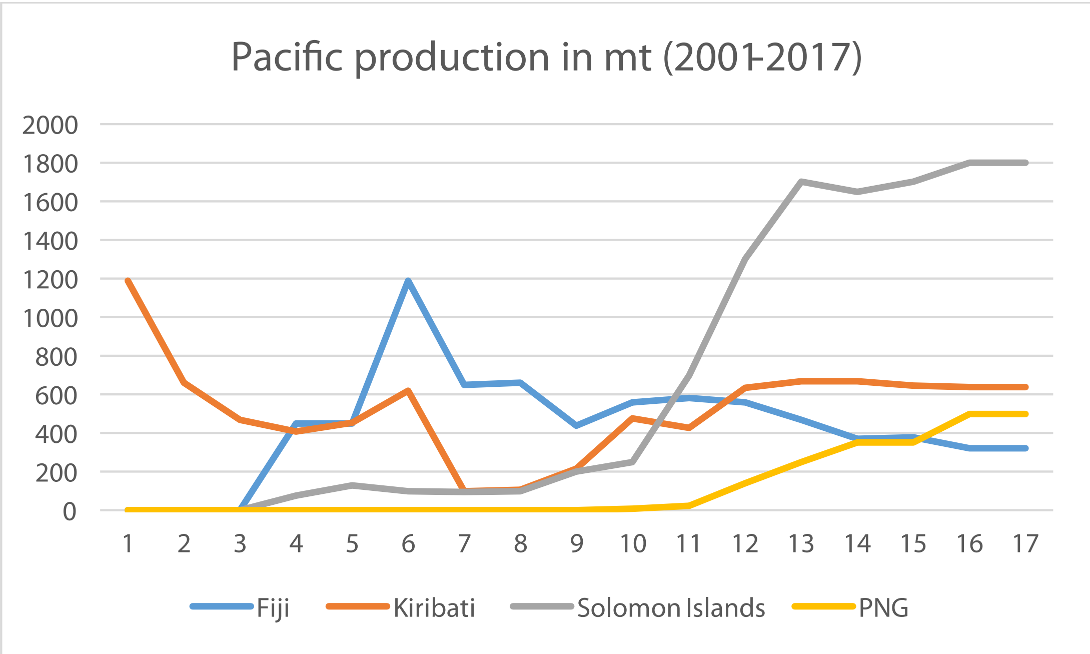

Figure 15. Estimated Pacific production in metric tonnes (dry weight) from 2001-2017

Figure 16. Seaweed farming community in Solomon Islands

Solomon Islands

The first trials were carried out in the Solomon Islands between 1986 and 1988 under an Overseas Development Funding project, using stock from Fiji. These trials were carried out at Vonavona and Rarumana districts in the Western Province. Mixed results were obtained at Vonavona due to heavy grazing by fish. Results from Rarumana, on the other hand, were promising, with 8 t (dry) harvested during the first year. Farming trials started again in 2000 under the European Union (EU) Special Interest Group funding, by using seed stock from the Vonavona site. From 2004 to 2008, the EU-funded project "Commercial seaweed production in Solomon Islands" provided technical and financial support to the following districts: Wagina, Maneoba, Marau, Dovele, Saeragi and Buena Vesta. Wagina and Maneoba, with a total production of around 1500 t (dry weight) in 2017 are the most productive islands in the country. Five licences to grow and export seaweed were issued to companies between 2011 and 2017. However, only three of the companies are currently exporting seaweed; two of them are exporting to Asia (e.g., China, Malaysia and Indonesia), while the third one is exporting to Europe.

Farming activities in the islands of Wagina and Maneoba are currently involving around 1000 coastal families located in very remote, isolated communities. Public perception of the activity is extremely good, since it is an important additional source of income to many poor/vulnerable families.

In the past 3 years, seaweed farmers have been looking into adding commercial value to their product, as it is being done in other regions of the worlds, such as Asia and Africa. Several extension officers and farmers have been trained in pre-processing and processing techniques for the preparation of products derived from algae of high commercial value, such as edible products, gels and desserts.

Solomon Islands Government has also been considering the option of establishing a processing plant in one of the main producing islands, which could provide services, not only to Solomon Islands, but also, to other countries within the Region involved on seaweed farming, such as PNG, Fiji or Tonga. Processing will enable considerable value adding and reduce shipment volume to save on cost.

Figure 17. Drying facility in Solomon Islands

Solomon Islands is now the largest seaweed producer in the Pacific Region. The success of this farming activity is due to the following factors:

- Availability of suitable farming sites.
- Adequate and continuous training of

farmers.
- Fisheries and extension officers trained and skilled.
- Closely monitoring and follow up by extension officers and exporting companies.
- High quality product.
- Maintenance of strong commercial contacts with buying countries.

Some of the most important challenges and limitations faced by seaweed farmers in Solomon Islands have been identified for the purpose of this case study and are listed below:

- Work force shortage.
- Lack of entrepreneurship.
- There is a strong need for further research into farming and processing.
- Geographical isolation.
- Need for better governance to regulate the number of exporting licenses.
- No proper data recording from farming sites.
- Limited extension support, mostly in remote areas.

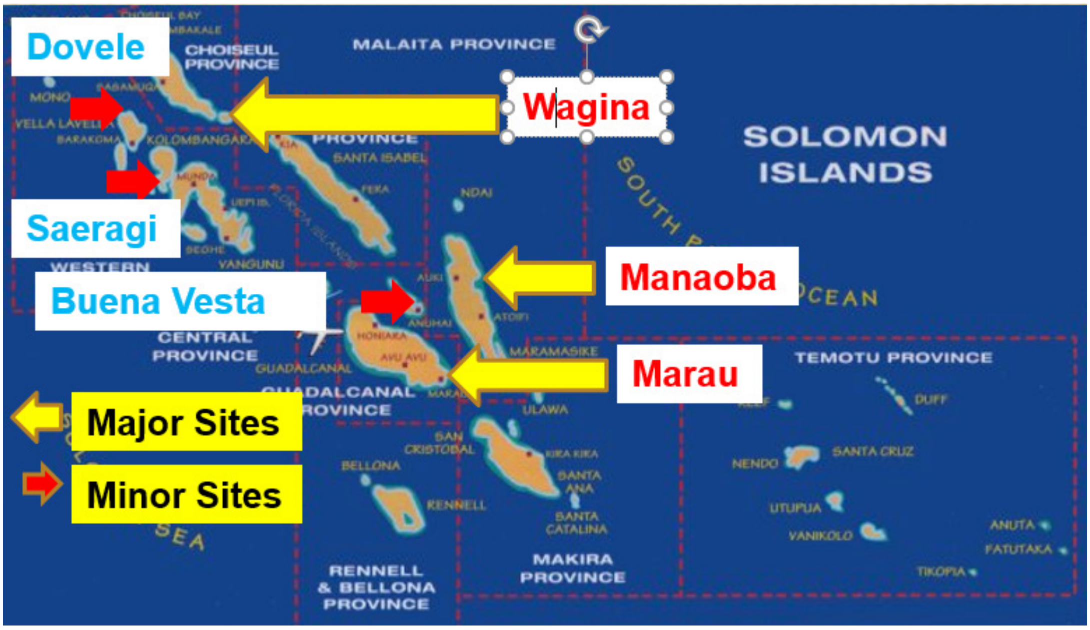

Figure 18. Major and minor production sites in Solomon Islands

Figure 19. Seaweed farmer showing a floating system in Wagina Island

Fiji

The first trials in Fiji were established during the 1980s with seedlings from the Philippines. Total production between 1985 and 1990 was around 684 tonnes, but ceased in 1993, and started again in 1997. Production is currently carried out in the following locations: Mau, Ono iLau, Gau, Kadavu, Tailevu North. The Government of Fiji is currently planning to expand seaweed-farming activities to several new locations in the country: Yasawa and Macuata islands, Cakaudrove in Vanua Levu, and other Lomaiviti islands.

Most cultivation is done by using the off-bottom method, nearby the coastal line where coastal communities can easily access the farming sites.

Floating rafts and floating longlines have been used with very promising results during 2013. Varieties used include tambalang and sacol. The new improved strain of the maumere variety was introduced to Fiji from Indonesia in 2012, in order to assess its performance in Fijian waters.

Most seaweed producers in Fiji are individual farmers living in isolated coastal communities.

Current production in volume is estimated at around 300 t (dry) for 2017, although the Ministry of Fisheries does not have accurate and exact figures. Production in value is relatively unknown. There are around 300 families involved in seaweed farming in the country, although this number is very variable and fluctuates depending on market prices of final product.

Figure 20. Off-bottom farming in Gau, Fiji

Figure 21. Off-bottom farming sites in Kadavu Island, Fiji

Figure 22. Seaweed specimen from a floating farm in Kadavu Island, Fiji

Kiribati

Commercial cultivation began in the mid-1980s in the Gilbert Islands. In 1991, farming and marketing activities were handed over to Atoll Seaweed Co. Ltd., but this company was dissolved in 2010. All production is currently being managed by another local company, CPP Ltd, which oversees the production as well as the export. There is no processing plant in Kiribati and dry product is being exported mainly to China and other Asian countries.

Figure 23. Seaweed farmers in North Tarawa, Kiribati

Most production in Kiribati is by individual farmers on the atoll Tabuaeran (aka Fanning Atoll) in the Line Islands, and is based on off-bottom and longline systems.

Major limitations faced by seaweed farmers in Kiribati are:

- Isolation.
- Water quality fluctuations, mostly related to climate change challenges.
- Limited extension support in isolated coastal communities.
- Limited access to inputs: high quality seedlings, farming equipment and technical skills.

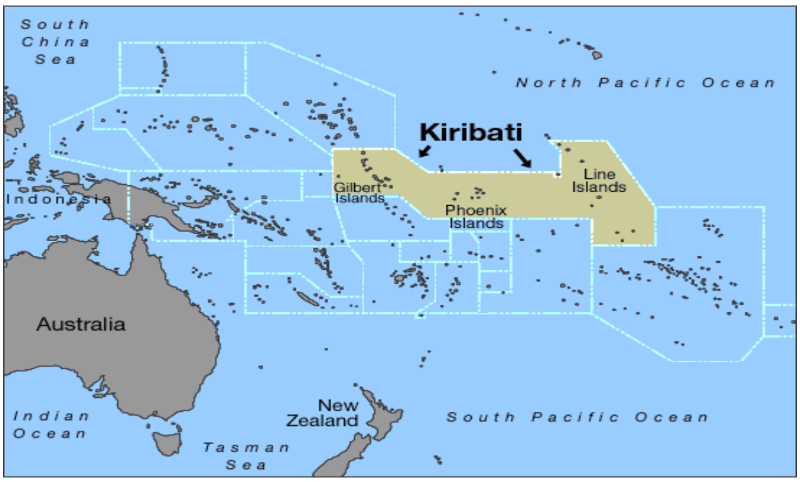

Figure 24. Map of Kiribati indicating the "Line Islands" group

Figure 25. Seaweed farmers with lines ready for harvest

Papua New Guinea

K. alvarezii (tambalang variety) was introduced into PNG in 2010 by a Malaysian company, to the Alotau region within the country, and was under trials until 2012. The production in this location has been increasing slowly since then. Seaweeds are also cultured in the Autonomous Province of Bougainville (APB), where individual farmers initiated seaweed production in 2011, with seedlings provided by farmers from Solomon Islands, with promising results.

Figure 26. Map of Papua New Guinea and major farming sites (Bougainville – red arrow and Milne Bay – green arrow)

In the case of Alotau, the company managed to successfully propagate sufficient seed for distribution to farmers, and 500 farmers became engaged in seaweed culture by using floating longlines and off-bottom farming systems. Total production in volume in 2017 was around 150 t (dry weight). The first shipment of semi-processed seaweed was carried out in December 2012 and exported to China.

In the APB, farming activities began in 2011, and production was around 120 t in this first year of cultivation and around 600 t (dry weight) in 2017. There are no accurate data regarding production in value and exact number of farmers in Bougainville, although it is estimated that more than 1000 seaweed farmers are involved in this region.

Figure 27. Seaweed specimen in a floating device in Alotau, PNG

Limitations

The main limitations identified by seaweed producing countries during the preparation of this paper were: limited skills and expertise on seaweed farming and harvesting strategies, and poor processing techniques. These constraints affect the seaweed sector at all levels — farmers, processors, middlemen, fisheries officers and extension services. Farming and processing techniques need to be better adapted to suit local conditions within the Pacific Islands region (e.g., water temperature and salinity fluctuations, and high average rainfall). Farmers in most Pacific Island countries need to receive improved extension support from fisheries officers, which currently limits future development and expansion of the seaweed sector. In addition, most farmers have limited access to cash, markets and equipment.

Isolation in terms of distance from markets and main ports, as well as inaccessibility of farming sites in most seaweed producing countries have also been identified as major constraints, thus resulting in high transportation costs and poor storage of seaweed products over long periods of time.

Pacific Island seaweed farmers are not very entrepreneurial, and farming organizations, if they exist, are relatively weak, and receive little support from public institutions. Legal frameworks governing mariculture activities are also weak given the size of the sector but need to be reviewed to facilitate development for large scale as well as community based farming.

Lastly, because there are no accurate data on production from certain farming sites, marketing strategies and development are difficult to carry out, as are the design of management plans and future extension programmes.

Future trends

The region's fisheries officers involved in seaweed cultivation as well as farmers are testing **improved strains and new varieties of seaweed** that may be better adapted to suit local conditions. Exchanges of genetic material are most likely to continue and possibly increase in the near future between Asian countries leading seaweed farming globally and Pacific countries.

Improved and better-adapted farming techniques should also be assessed and developed, including floating rafts, floating longlines, and rotational systems.

The **selection of farming sites** takes into account not only water quality parameters (e.g., temperature, salinity, currents, sea bottom substrate), but also the social, cultural, religious and economic aspects of the communities involved.

The **skills and knowledge level** of farmers needs to be increased, and should include training in the use of various techniques associated with farming, harvesting and processing. In addition, farmers associations should be promoted.

Most fisheries divisions and administrations within the four major seaweed producing Pacific Island countries are looking at different ways of building the capacity of their extension services with regard to seaweed farming, processing and harvesting.

Fisheries administrations within most countries in the region are well aware of the importance of proper **quarantine protocols and biosecurity measures** that are necessary to minimize and mitigate possible environmental and pathogen-related risks.

Lastly, the seaweed sector (farmers and companies involved) in the four main producer counties is assessing possible ways to produce **a semi-processed product** that will reduce freight volumes, and help make the industry economically feasible.

Summary of major regional trends

- Improved strains and new varieties (maumere) better adapted to local conditions.
- Improved farming techniques - floating rafts, floating long lines, rotational systems,etc.
- Assessment of socioeconomic aspects.
- Improved site selection methods.
- Promotion of farmer clustering to increase production volume and market efficiency.
- Capacity building on seaweed farming and processing.
- Extension services.
- Responsible quarantine protocols for new species and strains introductions.

Conclusions

Seaweed farming offers many opportunities for low cost income generating activities in PICTs. It can be an important economic boost for the less-developed outer islands, where few alternative income-generating opportunities exist. Seaweed farming from this region can make a useful contribution to supplement other world sources. From an environmental perspective, the Pacific region is also ideally suited for the farming of seaweed albeit with some adjustments in techniques and strains required between sub-regions and/or countries.

The successful, commercial production of seaweed in the Pacific is based on one single species, *Kappaphycus alvarezii*, which is primarily grown in Fiji, Kiribati, Papua New Guinea and Solomon Islands. Although there is a wide range of suitable habitats for seaweed farming in the region, a number of limitations constrain production and export, including isolation and distance from markets, small volume of production, vulnerability to world price fluctuations, socioeconomic issues, and limited skills and capacities for culturing seaweed.

Seaweed culture has been heavily promoted in Pacific Island countries because it requires a low level of technology and investment, can be operated at the family level, has relatively little environmental impact, does not require refrigeration or high-tech postharvest processing within the country (because it is a non-perishable product), and is normally compatible with traditional fishing and other nearshore subsistence activities. It is also an activity that can provide income and empowerment for women.

5. General conclusions

Pacific aquaculture is based and most probably, will continue to be based on aquatic exotic species. Those introduced species provide opportunities for commercial and community/family based famers to contribute to food security and/or generate income in a way that is no yet possible with endemic species. Four out of the top six farmed aquatic species in the Pacific are exotic, and they account for more than 90% of the aquaculture both in volume and value. The long term environmental impact of the introduction of exotic species remains however difficult to quantify given the paucity of scientific reports and assessments on the impact of most farmed exotic aquatic species in host countries. There is however raised awareness regarding the potential detrimental impact of invasive species in the region. The trend of introducing new exotic aquatic species is now decreasing and it is giving way to the introduction of exotic “improved” or “better adapted” strains, breeds and varieties (i.e., already introduced) as happens in the rest of the world. All new introductions are now subjected to systematic import risk analysis in line with biosecurity strategies being implemented at country and regional level. In a region where much still needs to be done for developing aquaculture as a significant alternative for food security and income, the balance between benefit and risk of exotic species introduction is slowly being reached and this leads to more sustainable practices in the future.

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