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THE SUSTAINABILITY OF QUEENSLAND'S CORAL HARVEST FISHERY

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FOREWORD

The Queensland Government commenced a formal management planning process for the Queensland Aquarium and Coral Collecting Fisheries by releasing a Discussion Paper in 1999. The community and government agency comments on that paper revealed an enormous range of divergent views and public feelings on the future of a coral fishery in the Great Barrier Reef Marine Park.

It was therefore evident that defendable, highly regarded scientific advice was needed to assess the future of the fishery. Such independent scrutiny was essential to reconcile the many issues surrounding the management of the fishery in Queensland.

The CRC Reef Research Centre kindly agreed to the request of the Queensland Fisheries Service's Harvest Fisheries Management Advisory Committee (Harvest MAC), to review the management of the coral fishery, and provide an authoritative statement on the sustainability of the fishery.

Community discussion surrounding the impacts of collecting coral is often emotive and based on unfounded concerns about the environmental impact. In contrast, the CRC Reef Research Report has been well received by the community, government and fishers alike. It has provided highly respected advice on the impacts of the fishery on the Great Barrier Reef Marine Park World Heritage Area.

This report has been crucial to the future of the coral fishery, and will form the basis of sustainable, sound and appropriate management arrangements in the fishery.

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EXECUTIVE SUMMARY

Queensland's coral harvest fishery is small by international standards, and is regulated by both input and output controls. Only 25% of the Total Allowable Catch (TAC) of 212 tonnes is currently harvested, including approximately 25 tonnes of live coral and 25 tonnes of rubble and 'living rock' (a reef substrate used in aquariums). The total value of the fishery is estimated $0.5 million per year.

The nature of the fishery in Queensland has changed over the last two decades with 34 of 36 fishers currently reliant on the sale of live corals for aquariums. About 60% by weight of live corals harvested, and all the living rock and rubble component of the harvest are for the aquarium coral market. Two abundant coral taxa (Families Pocilloporidae and Acroporidae) are primarily targeted for the ornamental coral trade, while the aquarium market targets small colonies of a wide variety of hard coral and soft coral species.

The total harvest in the fishery is very small relative to the coral cover on the Great Barrier Reef (GBR), and the capacity of the reef to accumulate calcium carbonate material. It does not represent a risk to the integrity of the reef system on either a reef-wide or regional scale. The potential impacts of the coral harvest fishery in Queensland are localised and are many orders of magnitude smaller than those resulting from other impacts such as cyclones, coral bleaching and predation by the crown-of-thorns starfish. On reefs which have been subjected to degradation as a result of coral bleaching or crown-of-thorns starfish predation, coral harvesting should be avoided to assist recovery of the coral communities.

An extensive study in 1985 evaluated the ecological sustainability of the ornamental coral fishery. The study that the fishery was sustainable because the target corals grew rapidly and recruited well, and the fishery was small and restricted to limited areas. The current take of these species is currently lower than it was at the time of the study in 1985.

The species targeted by the aquarium coral industry are generally small colonies (<15 cm diameter) of large-polyped species which survive well in aquaria. Many of the

target species are locally abundant but patchily distributed. The favoured habitat for most of these species is deep (10m to 25m), turbid water. Little detailed information about the distribution and life history is available for some of the target species. The life history of the majority of corals allows for broad dispersal of their reproductive products providing for replenishment of populations from nearby reef areas. Coral colonies also reproduce vegetatively, by budding or from the dispersal of fragments.

Where there is uncertainty about appropriate and sustainable harvest levels for particular species, an appropriate management regime should be implemented, including: protecting a significant percentage of reefs within a region from harvesting; species-level analysis of take to provide detailed Catch Per Unit Effort (CPUE) data; and collection of further information about the distribution and ecology of harvest species.

The current management regime involves 50 small fixed leases (collection authorities) which contain few corals suitable for the aquarium trade. The fact that the current management regime is inappropriate for the fishery is recognised by both fishers and fisheries managers. The Total Allowable Catch (TAC) should be reduced to more closely reflect the current much lower level of catch in the fishery, thus removing latent effort from the fishery. Separate catch quotas should be set for the living rock/rubble and live coral component of the fishery.

Roving licences, i.e. collection within the general use zones of the marine park, are favoured by the industry. However, they have been opposed by the Great Berrier Reef Marine Park Authority (GBRMPA) on the basis of their potential to increase conflicts between users, difficulty in assessing compliance, and increased difficulty in monitoring impacts. Management of the fishery on a whole–reef basis, with harvest permitted on a percentage of general use reefs, would address many of these concerns. This management regime would be consistent with the objectives of GBRMPA's Representative Areas Program that aims to zone reefs on a whole-reef basis. Spreading effort over a wider area than allowed under the present management regime would minimise visual impacts and enhance recovery from collection. It would provide for a large percentage of reefs to remain as replenishment areas, and allow monitoring of compliance and environmental impacts.

Management of real or perceived conflicts with other reef users is a significant issue for the fishery. Designation of collection areas must minimise the risk of conflict. Re-designation of most collection sites in deeper, turbid locations would benefit the industry and reduce conflicts with the tourism industry, which seldom uses such areas.

Farming of corals (collection and growth of coral fragments) is encouraged overseas to increase industry sustainability. Farming of corals from larvae or fragments, while ecologically feasible, is probably not financially viable in the current Australian market.

1. INTRODUCTION

The coral harvest fishery in Queensland is a relatively small fishery that supplies hard corals, soft corals and anemones to both the coral aquarium trade and the coral curio (ornamental) industry. The extent of the fishery is currently limited by collection quotas and a prohibition on the export of corals from Australia for private or commercial purposes under the CITES convention (Export of Coral Notice No 15 and 42).

In 1999, the Queensland Fisheries Management Authority (QFMA) began developing a management plan for marine fishes taken for aquarium displays, and for coral taken for aquarium display and ornamental purposes. The Harvest Fisheries Management Advisory Committee (Harvest MAC) was established by the QFMA to advise on appropriate management arrangements for the sustainable use of the harvest fisheries in Queensland.

As part of the process of developing a management plan, the QFMA released a discussion paper in 1999 for public comment. The process stalled following the call for public comments. The QFMA has subsequently been restructured and in June 2000 was subsumed into the Queensland Department of Primary Industries to form the Queensland Fisheries Service (QFS).

The CRC Reef Research Centre was approached by Harvest MAC to produce a report on the ecological sustainability of the coral harvest fishery. The objective of the study was to provide an authoritative synthesis of information about the sustainability of the coral harvest fishery, to assist in the process of developing a management plan for the fishery.

2. THE STATUS OF QUEENSLAND'S CORAL HARVEST FISHERY

Coral harvesting has been regulated in Queensland since 1932, when the industry supplied the souvenir market. The market for ornamental corals increased until the 1980s when Oliver (1985) reported that 86% of coral harvested was used for souvenirs, and 10% as dead corals in aquaria. Only 4% of specimens were collected for live aquarium specimens. In 1983, there were only 12 active collectors, and one species, *Pocillopora damicornis* (trade name brown-stem), made up 70% of the catch, making the fishery relatively easy to monitor and manage (Oliver and McGinnity, 1985).

In the late 1980s there was a rapid shift in the marine hobby aquarium industry, so that techniques to maintain living corals and other invertebrates in aquaria were available for the first time. This resulted in a change in the nature of the coral harvest fishery. Presently, less than 30% of the total harvest is destined for the ornamental coral market which includes dead corals for aquarium decorations and for crafts and curios. There are currently 36 participants in the fishery, who used 50 authorised coral areas in 1999. Only two participants in the fishery collect significant amounts of coral for the ornamental trade, with the remaining 34 mainly supplying the aquarium market.

The Total Allowable Catch (TAC) in each lease area is 4 tonnes per year, producing an industry-wide TAC of 212 tonnes. This TAC includes collection of coral rubble and 'living rock' (dead coral fragments with attached algae and invertebrates which form an important substrate in aquaria). In 1998-99, the industry collected around 50 tonnes, with approximately 50% of the total being living rock, coral rubble and sand (Table 1). Another small but significant proportion of the catch comprised soft corals, anemones and other Cnidarians. The current fishery exploits only about 25% of the TAC, which is probably indicative of the shift to smaller coral pieces of higher commercial value in the aquarium trade.

This major shift in the nature of the coral fishery has not yet been accompanied by commensurate changes in the management regime. Major management fishery issues include the following: current coral leases do not encapsulate the habitat and depth range inhabited by popular aquarium species; weight is an inappropriate measure of catch for living and soft corals; and species identification problems create issues for monitoring and management.

Table 1. Coral harvest as reported for years 1998 and 1999 with weight (kg) and numbers of specimens (QFS, unpublished data)

	1998		1999	
CATEGORY	**Weight**	**Nos**	**Weight**	**Nos**
Living Rock	25,875		16,523	
Coral Rubble	4,932		4,094	
Star Sand	398		1,005	
Coral Sand	319		286	
TOTAL SUBSTRATE	**31,524**		**21,908**	
Pocilloporidae	7,062		8,162	
Acroporidae	7,002		6,528	
Poritidae	2,669		2,940	
Caryophyllidae	2,422		2,232	
Fungidae	1,152		1,332	35
Faviidae	1,150		1,116	
Dendrophylliidae	647		230	
Mussidae	163		138	
Pectiniidae	33		76	
Duncanopsammia	69		30	
Merulinidae			15	
Siderastrea			14	
Trachyphyllia	3		5	
Gardineroseris			5	
Oculinidae			4	
TOTAL HARD CORAL	**22,372**		**22,827**	
Soft Coral/ Alcyonacea	591	4,601	1,268	4720
Tubiporidae	109		55	
Nephtheidae	5			1
Sarcophyton		71		9
Xeniidae				2
Gorgonacea	119		329	
Clavulariidae				14
TOTAL SOFT CORAL	**824**		**1,652**	
Blue Coral			80	
Milleporidae			45	
Corallimorpharia	21	2,746	431	1371
Zoanthidea	102		120	
Sea anemones		1,037		854
Other			13	
TOTAL OTHER CNIDARIANS	**123**		**689**	
TOTAL	**54,843**		**47,078**	

Coral collecting authority sites have been allocated historically on the basis of the occurrence of popular ornamental coral taxa such as *Pocillopora* and *Acropora*. These taxa now represent a smaller proportion of the take. Similarly, collection authorities are limited in depth to 6 m, but the main target species for the aquarium trade are more abundant in deeper water. Coral harvest figures for 1998 and 1999 are presented in Table 1.

Reports from the industry indicate that 50% to 70% of the Pocilloporidae and Acroporidae collected is destined for the ornamental coral market (QFS, unpublished data). This would indicate that in 1999, about 10 tonnes of the total harvest of 22 tonnes of hard corals was destined for the ornamental market, while the aquarium coral market accounted for around 12 tonnes of live hard coral, 1 tonne of soft coral, and 20 to 30 tonnes of living rock and rubble.

The financial returns on sale of live corals in the aquarium trade are likely to be higher for each coral piece than sale into the curio market. Oliver (1985) reports that small coral fragments made into curio pieces sell for $1 - 5 each. In the recent past, ornamental corals were sold by the tea-chest. Fishers report that living coral pieces wholesale in Australia for $3 - 20 and retail for $15 - 40 for common corals, and sell for up to $100 for special pieces. However, collection of living aquarium corals requires greater capital equipment and time because the corals must be transported in water rather than dry on deck. Handling and storage costs are also higher, with freight from north Queensland to southern states reported as effectively doubling the wholesale cost of the corals.

A social analysis of Queensland fishers (Fenton and Marshall, 2001) reported information on harvest fisheries and flow-on social and financial effects in the adjacent coastal communities. They estimate the value of the coral harvest industry in Queensland in 2000 at $427,000, with the average Gross Value of Production at $11,700 per fisher. Many coral harvest fishers also collect aquarium fish (QFMA, 1999), which provides a higher average GVP (Fenton and Marshall, 2001). About 40% of harvest fishers who rely on aquarium products, including corals and aquarium fish, are based in the Townsville to Port Douglas area, 30% in the Mackay to Gladstone region and 30% in the south-east Queensland region.

3. ECOLOGICAL SUSTAINABILITY OF THE CORAL HARVEST FISHERY

In contrast to many international fisheries (see section 7), Queensland's coral harvest fishery has the benefit of extensive reefal areas, a low intensity fishery, and a strong reef management regime. QFMA (1999) reported that the current Total Allowable Catch (TAC) of 212 tonnes is collected from a Great Barrier Reef reefal area of 340,000 km^2, at a rate of less than 1 tonne per 1651 km^2 annually. As reported above, only 25% of the TAC is presently harvested, of which only 50% is live coral. The question of concern to both fishers and managers is whether the current management regime is appropriate for the industry, and whether the current and alternative management regimes are ecologically sustainable.

QFMA (1999) calculated that if all corals were collected from within the designated lease areas, this would represent a harvest of less than 1 tonne of coral per lease of average size of 25,000 m^2. This represents 1-2% of the standing stock of corals within the lease area, which is well within the annual growth potential of coral species.

One Tree Island is the best-studied reef from a geological perspective on the Great Barrier Reef. It has a net accumulation over the last 8,000 years of 150 x 10^6 tonnes of $CaCO_3$, (Davies, 1983) at a rate of 1,875 tonnes per year. Because One Tree Island is at the southern limit of the Great Barrier Reef and is small in area, this figure is likely to be an underestimate for the average reef. This means that the 2,500 reefs on the Great Barrier Reef accumulate more than 5 million tonnes of $CaCO_3$ per year, of which 50 tonnes is presently harvested. It is clear that coral harvest fishery is insignificant with respect to the structural integrity of the Great Barrier Reef.

The taxonomic composition of Queensland's coral harvest for 1998 and 1999 are presented in Table 1. Living rock and rubble represent around 50% of the total harvest. The dominant taxa were Pocilloporidae and Acroporidae (14.6 tonnes total in 1999) representing 64% of the coral take. Of the other taxa, only Poritidae, Caryophyllidae, Fungiidae and Faviidae were collected in quantities greater than 1 tonne.

Living rock, rubble and sand

Living rock, rubble and sand are the most abundant component of most reefs and are generated as a result of natural coral mortality and accretion. Pieces of living rock suitable for the aquarium trade are usually around 0.5 kg in weight. The rocks generally have a biological coating, primarily of turf algae, with some small encrusting invertebrates such as patches of bryozoans and sponges. The industry does not favour rocks with a high biomass to substrate ratio, because the death of the biota in aquaria can pollute the water and kill the aquarium organisms.

This type of substrata is extremely common in many reef habitats including reef flats and at the base of the reef slope. Only pieces of a suitable size and appearance are collected by the Queensland fishery, leaving the large majority of the standing stock untouched. Limestone rock and rubble are continuously produced in a functioning reef, and at the present level of take, its harvest will not affect reef structure and function on either a local or a regional scale. Internationally, the take of coral substrate using implements such as crowbars is sometimes focused on accessible part of the reef flat causing localised damage and is a significant environmental concern.

The ornamental coral fishery

Oliver (1985) and Oliver and McGinnity (1985) evaluated the coral harvest fishery in the early 1980's and concluded that the coral collection industry posed little threat to the Great Barrier Reef. The industry was almost certainly below the level of sustainable yield because: collection was permitted on <1% of reefs in the Great Barrier Reef region; repeated collection within a lease area had been possible over periods of 5-6 years (although there was evidence that some corals were collected outside the leases); and annual production of *Pocillopora damicornis* in particular far exceeded the allowable catch.

The current take for *Acropora* and *Pocillopora* (14 tonnes) is around a third of what it was in 1982-83 (44 tonnes, Oliver, 1985). Because of the high productivity and potential for recruitment of these taxa, the ornamental fishery does not represent a threat to the Great Barrier Reef on either a reef-wide or regional scale.

A few coral leases of significance to the ornamental coral fishery are located on inshore reefs that have been affected by coral bleaching in recent years. Where reefs have been impacted by either natural (cyclones, coral bleaching, crown-of-thorns starfish) or anthropogenic activities, coral harvesting should not take place so that the recovery of the reefs can proceed unimpeded. This is consistent with the best interests of the industry, which would find few suitable corals in these depleted areas. Under the present system, there is little flexibility in moving coral authority areas in response to environmental changes.

The advantage to managers of the coral ornamental fishery in the past was that the species targeted in the fishery (*Acropora* sp. and *Pocillopora* sp.) were common, had relatively rapid growth rate, and were amongst the most successful recruiters and early colonisers of all coral species. In addition, colonies were known to survive the removal of fragments when a significant part of the colony could be left intact, and there is some evidence that large fragments left behind could also regenerate colonies. Growth of *Pocillopora damicornis* branches is about 2 – 3 cm per year, and for branching *Acropora* colonies is 5 – 10 cm per year (reviewed in Harriott, 1999), allowing rapid growth and recovery of these species. Information on the abundance and distribution of these species is summarised in Table 2.

The aquarium coral fishery

The taxa targeted for the live aquarium fishery vary considerably between different participants in the fishery. Fishers all collect live-rock which represents 40% to 70% of their take. With respect to live coral collection, some fishers concentrated primarily on soft corals, others collected significant quantities of branching *Acropora* and *Pocillopora* corals with a range of massive species, and another collected a wide range of soft corals and primarily massive hard corals.

For the colonies of *Acropora* and *Pocillopora* collected for the live aquarium trade, issues with respect to sustainability are similar to those described above in the section on ornamental corals.

Table 2. Demand, geographic distribution and abundance of coral species targeted for the ornamental and live aquarium trade. Information is derived from Veron (1986), input from coral biologists, and advice from coral collectors about their target region. Shallow = generally hard substrate, < 10m; Deep = generally muddy/sandy substrate, > 10m. Abundance is on a scale where: 0= uncommon or not targeted; 1= patchily distributed but locally abundant; 2= widespread but not common; 3= widespread and common.

CORAL TAXA	CURRENT DEMAND	Northern to Central GBR (Cairns/Townsville)		Central to Southern GBR (Mackay to Rockhampton)	
		Shallow	Deep	Shallow	Deep
Ornamental fishery	**~ 10 tonnes**				
Acropora	High	3	0	3	0
Pocillopora	High	3	0	3	0
Fungia	Med	1	1	1	1
Turbinaria	Low	2	2	2	2
Live aquarium corals					
Hard corals	**~ 12 tonnes**				
Acropora	High	3	0	3	0
Pocillopora	High	3	0	3	0
Catalaphyllia	High	0	1	1	1
Euphyllia	High	2	2	2	2
Plerogyra	Mod	2	2	2	2
Duncanopsammia	High	0	1	1	1
Goniopora	High	1	1	2	2
Blastomussa	Mod	2	2	2	2
Cynarina	Low	0	2	0	2
Faviids	Mod	3	3	3	3
Other Mussids	Mod	3	3	3	3
Heliofungia	Mod	2	2	2	2
Soft corals	**~ 1 tonnes**				
Sarcophyton	Mod	2	2	2	2
Lobophyton	Mod	2	2	2	2
Sinularia	Mod	1	2	2	2
Alcyonium	Mod	2	2	2	2
Zooanthids	Mod	1	0	2	0
Corallimorphs	High	0	2	1	2

Favoured species in the Australian coral aquarium trade are listed in Table 2. Many of these species are less abundant in most shallow reef areas than the branching corals favoured by the ornamental coral fishery, and many are patchily distributed.

Information about their distribution, derived from a variety, of sources is summarised in Table 2. Many species are common in inshore areas, and areas with sandy or muddy substrata, and several are locally abundant on sandy substrata deeper than 20 m off the edges of reefs. There is relatively little published quantitative information about the abundance at species level of the target corals on the Great Barrier Reef. Coral harvesters are a potentially useful source of information about these species, which are seldom seen in the shallow areas where most coral biologists work. Such information could be a valuable supplement to the sources presently available about the distribution of coral species in the inter-reefal areas of the Great Barrier Reef.

Growth rates of most of massive coral species are lower than for branching corals - in the order of 2 - 4 cm per year increase in colony diameter (Harriott, 1999). There is very little information about their recruitment potential as none of these taxa form a dominant component of juvenile corals in recruitment studies, which are dominated by the fast-growing and rapidly recruiting *Pocillopora* and *Acropora* species (Harrison and Wallace, 1990). Most of the target taxa have broadcast spawning so they can potentially produce larvae that can be dispersed large distances and replenish distant reefs (Harrison and Wallace, 1990).

Detailed scientific information about the taxonomy and species-level distribution of soft coral species in Australia has been lacking until very recently (Fabricius and Alderslade, 2001). In general, soft corals represent a significant proportion of coral cover on many reefs, in the range of 5 - 15 % cover. Many species grow rapidly and occupy space by extending vegetatively. In some sites, there has been concern that soft corals potentially occupy large reef surfaces after mortality of hard corals, for example, as a result of predation by crown-of-thorns starfish. They generally appear to survive well in aquaria.

More biological information about the species targeted by the aquarium trade would assist managers to develop more appropriate management regimes. Detailed information on corals appropriate for the aquarium industry, which can survive for long periods in aquarium conditions is still largely unpublished. Experienced hobbyists are extremely knowledgeable about this topic, and the collation of information from this sector would be useful. It has been suggested that corals should be graded with respect to difficulty to maintain in aquaria, and more advice on appropriate husbandry conditions should be provided at the point of sale to the public to reduce wastage for collected aquarium specimens. Further research about the survival of corals in aquaria under different conditions would allow targeting of species which would not need to be replaced frequently.

Collection by the industry of detailed data on location of collections at the level of coral species or genus would provide useful information on coral distribution. Such data would also allow more detailed assessments of sustainable yields to be made. Research supported by the industry on the life histories and distribution of these coral species would be useful to the industry, managers and the scientific community.

Coral life histories and replenishment

Corals reproduce either by releasing eggs and sperm which are fertilised in the water column to form small larvae called planulae, or by releasing larger planular larvae which develop internally (brooded) following internal fertilisation. The former generally spend 3-10 days in the water column before settling onto the reef often kilometres from the reef of origin, while the latter are often capable of settling quickly and close to the parent colonies. Coral populations recover from harvesting either by regrowing from the intact base, if part of the colony is left, or by larval settlement and growth of a new colony. Both types of recovery are common after any type of natural (cyclone, disease, coral bleaching) or human (diver damage, ship groundings) impact.

Recovery of sites from high levels of damage, such as that following crown-of-thorns starfish predation or severe cyclonic damage, may be rapid (i.e. recovery from very low to normal coral cover within 10 years) provided the area receives a supply of larval corals from either nearby or distant reef areas. Recent research is assisting in identifying reef areas which are either significant sources or sinks for marine larvae (Bode, personal communication), although the research is not yet at a stage where it can be used to make detailed predictions for individual reefs useful to management.

Where part of a colony can remain intact, a colony can recover more quickly than if larval settlement is required. For any species which will regrow from a part-colony, managers should encourage a practice that only part of the colony be collected. This will be particularly appropriate for the ornamental coral fishery which targets primarily branching coral species. It will not be appropriate for all species, e.g. some massive colonies are unlikely to survive well if the colony is broken into pieces.

Where reefs in each region are protected from the harvest fishery, including those reefs designated as highly protected 'green' reefs, the populations of harvested species on these reefs will provide a source of coral larvae which can potentially recruit to nearby harvested reefs. Within each reef, not all colonies of the target species will be suitable for collection, nor will all colonies of a target species be located, so a local source of coral larvae will also remain to assist replenishment.

Subtropical coral areas

Another issue for the Queensland coral harvest fishery, is the lower availability of coral south of the Great Barrier Reef (Banks and Harriott, 1995) where several coral authorities are granted for sites in south-east Queensland. There is also considerable evidence that corals grow more slowly at higher latitude sites (Harriott, 1999), and that coral recruitment rates are low in south-east Queensland (Banks and Harriott, 1996). Therefore, the more southern coral leases are likely to support a lower sustainable yield than sites on the Great Barrier Reef and may require lower quotas and closer monitoring to ensure that coral populations are not depleted. A similar recommendation has been made for the reefs of Florida, Gulf of Mexico and the Southern Atlantic on the grounds that low growth rates of corals at these sites make them equivalent to a non-renewable resource (Anon 1982 and Jaap, 1984 cited in Oliver and McGinnity, 1985).

4. ALTERNATIVE MANAGEMENT OPTIONS AND THEIR IMPACT ON SUSTAINABILITY

Present regime - fixed collection areas

Coral collection is currently licensed from approximately 50 fixed areas in Queensland. There are presently input controls with limits on the number of fixed coral authorities, and on the number of boats and collectors. There are also output controls which limit the total coral catch quota associated with each collection authority. At present, the overall coral harvest is only about 25% of the TAC.

The current management regime is no longer appropriate for the fishery. The quota is significantly larger than the present take; the management regime is not consistent with changes to a primarily live coral trade in recent decades; there is no monitoring of the sustainability of the industry; and there are no clear objectives for the management of the fishery. The revised management plan is intended to address many of these issues. Because of the changes to the fishery, it is clear that current lease areas are inappropriate for most of the fishery. There is relatively little compliance monitoring to assess whether fishers are collecting outside the designated lease areas.

The main benefits of restricting coral collection to small lease areas are twofold: it allows monitoring of the impacts of collection on the permitted area; and reduces conflict with other users. Limited resources have not previously allowed any monitoring of coral authority sites in this way in Queensland. Such monitoring assumes that all authorised collection has occurred within the permitted area, which is unlikely to be a realistic assumption. The restrictions on the location of coral harvesting reduce the potential for conflict with other reef users, in particular with passive users who may resent the collection of corals which form the basis of their recreational or commercial activities.

Most of the existing coral areas need to be relocated due to their unsuitability to provide coral species demanded by the live aquarium trade. This would be a substantial cost and take some time, as a public consultation process would need to occur.

Rotating, fixed leases

Many coral fishers who hold multiple site leases have suggested that they voluntarily rotate the use of their leases, so that they do not use some leases in a single year (QFMA, 1999). Incorporation of such a strategy into the management of the fishery might permit a larger number of leases to be designated in sites appropriate for the fishery, with rotation of sites allowing more time for reef replenishment between harvest periods. The sites would be selected using similar criteria to those presently in use, i.e. containing target species, and avoiding conflict with other users. Monitoring the impact of the industry on the sites would be possible, and compliance monitoring would be similar to the present situation. Relocation of leases, as discussed above, would also be required.

Roving licenses

Because of the diverse coral taxa targeted for the aquarium market, commercial coral fishers have reported that existing leases, which were selected on the basis of the presence of ornamental coral species, do not contain the appropriate species mixture for their fishery. They have indicated a preference for collection of corals over a wider area than presently allowed, e.g. within the general use zones of the Great Barrier Reef Marine Park, in a similar way to other commercial fishing operations.

The Great Barrier Reef Marine Park Authority (GBRMPA) has indicated that they do not favour this option (Anon, 2000 a) because it limits the capacity to enforce the fishery and monitor its impacts. At present, primarily because of the small size and value of the coral harvest fishery, the impacts on lease sites are not monitored.

The environmental impacts of the fishery are likely to be less if collection effort is spread over a wider area, than from intensive collecting within a restricted area. The removal of corals over a wider area will be less visually noticeable, because adjacent corals will grow to replace the corals removed where coral density is high, and because small spaces where corals have been removed can receive new recruits from both close and distant colonies.

Management on a whole-reef basis

Another management option is to permit the coral harvest fishery on a subset of the reefs zoned for 'General Use'. Such a regime would be consistent with the objectives of GBRMPA's Representative Areas Program that aims to zone reefs on a whole-reef basis. This option also permits compliance monitoring in the same way as other reef activities.

The number of reefs on which coral collection is permitted can be limited, for example, to a maximum of 10% or 20% of general use reefs within a region. The reefs could be selected to reduce conflicts with other users as much as possible, and to contain the appropriate species for the live coral fishery. Sustainability of the industry would be largely ensured by preserving a large percentage of reefs to act as replenishment zones for the harvest reefs. The impacts of coral collection could be evaluated by statistically comparing population densities of targeted corals on harvest reefs with those on control reefs.

Species-specific quotas

Where the possibility of local depletion of an uncommon taxon is an environmental concern, specific output restrictions on harvesting of the less common species would be a useful management tool. In the present fishery, collection of live rock, hard coral, soft coral and other categories are covered by a single quota. There are currently no taxon-specific limits on coral collection, apart from *Fungia* corals. Such limits would require the provision of guides for identification of key taxa, and some monitoring of the taxonomic composition of catches to ensure compliance.

Species-specific quotas and records of collection will better protect species for which the sustainable yield is uncertain. Collection of such data will also provide more useful catch per unit effort (CPUE) statistics.

Minimising conflict with other reef users

A move from small fixed leases to collection over a wiser area may increase conflict with other reef users, in particular with the passive use of reefs by divers and snorkellers. This is a particular concern when the small economic value of these fisheries relative to the tourism industry is considered. Negotiation of a change in the location of harvesting would need to be managed in consultation with other reef users.

The preferred practices of aquarium coral collectors would minimise conflict with other users such as tourists, because target corals are generally found in depths of 10 – 25 m, while most tourism activity is in the upper 10 m of water. Coral collection authorities could be moved to deeper water and avoid overlap with most other users. In addition, many of the coral species are found in relatively turbid waters which are seldom used by the tourism industry.

Encouragement of coral culture for aquariums and/or ornamental corals

Some of the coral collection quota could be used to collect broodstock or small coral fragments which could be grown to saleable size in captivity or at protected sites (Section 5). Internationally, corals are advertised for sale on the basis of having been cultured for the aquarium trade, with the implication of increased ecological sustainability (Section 7). In Australia, the higher costs associated with culture of corals mean that while it is ecologically feasible, it is probably not a viable economic option, given the small domestic market for live coral.

5. CORAL CULTURE

Yates and Carlson (1992) reported on the successful propagation and growth of corals in aquarium systems and how this can reduce the need for coral collection for public and private aquaria. They provide data about corals that fragment naturally so that they can be collected without damage to parent colonies, and on their capacity to survive and grow in captivity. The Waikiki Aquarium, where much of their data was collected, has not reported successful rearing of corals from larvae.

Many of the taxa targeted by the international aquarium trade (*Goniopora, Lobophyllia, Euphyllia, Catalaphyllia, Plerogyra*) are listed as successful for aquarium rearing by Yates and Carlson (1992). The capacity of these species to be reared in captivity no doubt reflects their demand in the aquarium industry. There are anecdotal reports from the international aquarist community that corals reared in aquaria can be grown to a size where fragments can be exchanged with or sold to other aquarists. Enhanced capacity to grow corals rapidly in aquaria would reduce the need for collection of wild corals.

The primary technology used internationally for commercially 'farmed' corals is collection of coral fragments from the wild. The fragments are then attached to discs for support and mounting, and are usually kept on the farm for a period of 4-6 months (www.coralfarms.com/sol_farm.htm) before being sold and exported. There are similar farms in the Solomon Islands, Vanuatu and Fiji. All farms promote the competitive advantage of being environmentally sensitive and socially responsible and supporting local people in a sustainable industry.

If selected and collected carefully from the right species, attached coral fragments have high survival rates in the coral's first year of life relative to corals reared from larvae. Many coral species fragment naturally, and if positioned carefully, will begin to grow at rates similar to adult corals. An advantage of this method over collection of colonies or fragments at saleable size is that more small fragments can be collected from the 'donor' colony without affecting its ability to recover from the collection. This method is only suitable for the limited number of species with a branching growth form.

Difficulties with the coral culture process include: the difficulties in keeping coral alive in aquaria long enough for the grow-out to saleable size; and the need to find a protected oceanic site with suitable water quality where corals can be reared. Permits will be required where structures are needed for the farming operation. A proposal for infrastructure for a coral farm on the Great Barrier Reef has recently been rejected.

An alternative to culture of corals from fragments is to rear corals from eggs or larvae, reducing the necessity to collect corals from the wild, other than for brood-stock. Australian scientists have been pioneers in developing the technology to breed and rear corals experimentally in aquarium situations. The spawning times of many common coral species on the Great Barrier Reef are well known, both for brooding and for broadcast spawning corals. The main barrier to culturing corals from newly settled larvae is that juvenile corals have very high mortality rates in the field. Corals grow slowly in their first year of life so that a saleable coral of about 6 cm diameter reared from a larva is likely to be at least three years old. The length of time to harvest size and potentially high mortality of juvenile corals mean that this technique is unlikely to be financially viable in Australia in the near future.

6. FISHERY PERFORMANCE INDICATORS AND MONITORING OF FISHERY IMPACTS

The QFMA (1999) called for public comment on measures to monitor the health of the fishery and meet the objectives of the management plan. While the use of performance indicators in fisheries management is relatively new, having developed within the last decade, there is considerable research and development in this field both nationally and internationally.

A primary consideration in the development of performance indicators for management plans is that the objectives of the plans must be clearly defined, so that it is possible to measure whether those objectives have been achieved. Once clearly defined and measurable objectives have been documented, the data required to measure the outcomes of management against the objectives must be collectable.

A standard way of monitoring fisheries is to collect catch per unit effort (CPUE) statistics over several years. Lack of sustainability of the fishery would be indicated by an increase in the effort needed to fill the TAC. However, CPUE in dive-based fisheries (eg aquarium fish) has not proved to be a reliable measure, because searching time is usually not reported by fishers in logs. In addition, a shift in the fishery from a more valuable to a less valuable target species might indicate that the population of the preferred species had declined, even if total catch remained high. However, it could also reflect a shift in market demand.

To measure ecological sustainability, a fishery-independent monitoring program would be useful to ensure that coral cover and diversity within sites did not deteriorate over time. As discussed above, such monitoring is possible where fishing is restricted either to lease areas or to specific reefs, but would be very difficult for roving leases. On the Great Barrier Reef, the Long-Term Monitoring Program, based at the Australian Institute of Marine Science collects annually information on changes in coral cover for a sub-set of reefs on the Great Barrier Reef. Unfortunately, the scale of sampling for the program and the potentially high rates of natural change in the reefs means that such a monitoring program is unlikely to detect changes in coral cover caused by the harvest fishery.

The relatively low value of the fishery at this time (< $0.5 million for 36 fishers) means that no program currently exists to monitor the condition of coral leases. In addition, if fishers collect outside their leases, the assumptions of effort within authority areas may be invalid, so a monitoring program would have little value. If environmental monitoring was required in the fishery on a cost-recovery basis, the cost of monitoring might present a problem for lease-holders given the relatively small value of the fishery. The current low take in the fishery would not warrant the high cost of a fisheries-independent monitoring program.

As discussed above, the shift to a wider range of target species means that it is important to track the number of colonies and taxonomic range of species collected. Records of taxonomic status and colony size are required for compliance records. More rigorous reporting of collection records and their eventual markets could be required of coral wholesalers and retailers. Collection of suitable information on the location, species and size of corals collected would allow an evaluation of the potential for the fishery to impact on coral cover at the collection sites.

In many Queensland fisheries, compliance is monitored by the use of a Vessel Monitoring System (VMS). This would be a particularly useful tool in the coral harvest fishery where coral harvest authorities are site or reef-attached. However, the cost of the monitoring system may be prohibitive for such a small fishery, and is not suitable for many of the smaller vessels used in the coral fishery.

7. THE INTERNATIONAL MARKET AND TRADE IN CORALS

Export of corals from Australia is restricted because corals are classified on the CITES listing (Convention on International Trade in Endangered Species of Wild Fauna and Flora) as category II organisms (vulnerable to exploitation but not at risk of extinction). For trade in these species, an export permit is required, where the exporting country is satisfied that the export will not be detrimental to the species (Wells and Barzdo, 1991). In Australia, Environment Australia is responsible for decisions regarding coral export permits. No export of corals from Australia is currently permitted.

The trade in marine aquarium species from south east Asia to the USA and Europe is estimated to be worth US$200 million annually. The aquarium industry is very large in north America, with more than one million home aquarium hobbyists. Only 10% of these maintain marine aquaria, and a smaller percentage would attempt to maintain corals in aquaria (Baquero, 1999). The costs of establishing a 'mini-reef' home aquarium where corals can be maintained is expensive, at between US$300 and US$2000 per tank depending on the size.

The USA represents 70-90% of the international live aquarium coral market. Sale of corals into the large USA market is potentially lucrative. Prices within the USA are US$18 - 60 per piece of live coral, usually 3 – 15 cm in diameter (www.aquatictech.com/livestock.html; www.northcoastmarines.com). Analysis of the Canadian market (Baquero, 1999) indicated that the price to collectors in Pacific Island nations was in the order of $CAN 4 - 25 per piece, with an eventual retail prices of $24 - 100. In the same study, live rock provided $1.25 –2.00 per piece to collectors and retailed for $7 - 9 per piece. Coral fragments sold from US$13 per piece.

The current status of international trade in corals is reviewed in Green and Shirley (1999). The volume of sales of live coral internationally has increased more than six-fold in the last decade, to approximately 1.6 million pieces per year in 1998 (Green and Shirley, 1999; Bruckner and Davies, 2000). Apart from the USA, other significant coral importers are Europe, Japan and Canada, while the dominant coral exporting countries are Indonesia, Fiji, the Solomon Islands and Vietnam. The dominant coral species traded internationally are *Euphyllia, Goniopora, Trachyphyllia, Acropora, Catalophyllia* and *Plerogyra.*

Internationally, there is concern about the impacts of coral collection in countries where there is a weak reef management framework and little regulation of collecting activities, particularly in some Asian and Pacific countries (Wells *et al*, 1994; Green and Shirley, 1999). The report of the International Working Group of the United States Coral Reef Task Force (Anon, 2000 b) states that commercial harvest of corals and live rock can potentially cause localised destruction of coral reefs including increased erosion and loss of critical habitat. They support international initiatives such as: CITES and the International Coral Reef Initiative; continued consultation with coral exporting countries; support of environmentally-sound practices in coral exporting countries; and improved enforcement trade limitations in coral reef species. An international workshop on developing guidelines for ecologically sustainable practices for the coral trade was sponsored by NOAA Fisheries in Jakarta in April 2001.

Baquero (1999) notes that it is possible to provide high quality, healthy aquarium organisms with minimum mortality. Such practices would have the support of hobbyists, but no system is currently in place to document quality products and sustainable practices. The Marine Aquarium Council, based in Hawaii, has been established to develop appropriate standards and certification for international trade in coral reef species, including corals. The process of developing these standard should be tracked closely by the Australian aquarium industry.

8. CONCLUSIONS

Queensland's coral harvest fishery differs from many overseas situations where there are major concerns about environmental impacts of the fishery. In Queensland, a very small percentage of reef area is fished in a limited way to supply a small domestic market. The Great Barrier Reef Marine Park is also very well managed and regulated relative to many other coral reef systems.

In Queensland, the ornamental coral take is relatively small and targets coral species which grow and reproduce rapidly, so that there are few concerns about ecological sustainability. The live aquarium coral take focuses on small numbers of a wide variety of large-polyped coral species. The distribution of these species is patchy, and relatively little is known about their ecology so that their commercial take needs to be limited and carefully monitored. However, while the collection remains restricted to a small percentage of the available coral reef area, natural recruitment and growth processes should ensure replacement of harvested corals.

This report outlines several management options to enhance ecological sustainability of the coral harvest fishery. These include reduction of the Total Allowable Catch to remove latent effort; moving lease areas to habitats suitable for the target species and away from areas of conflicting uses; developing more effective compliance monitoring procedures; developing useful performance measures for the fishery; and establishing and tracking species-specific quotas on aquarium coral species. Incorporation of such practices into the management of the fishery would resolve many of the difficulties experienced by the fishery managers in recent years, but would increase the effort required by the fishery managers and the industry.

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