CHAPTER 15

Green Snail

Masashi Yamaguchi

I. INTRODUCTION

The green snail is a gastropod belonging to the Family Turbinidae. The main species of turban shells harvested in the South Pacific are the green snail (*Turbo marmoratus* Linnaeus, 1758), the rough turban (*T. setosus* Gmelin, 1791) and the silver-mouth turban (*T. argyrostomus* Linnaeus, 1758). *T. setosus* and *T. argyrostomus* are mainly targeted for food in the South Pacific region and their shells are discarded.

The majority of this chapter is concerned with *T. marmoratus*, the largest species of the family which grows to more than 20 centimetres (cm) in shell diameter and two kilograms (kg) in weight. It is herbivorous and its nacreous shell is highly prized for inlay material for lacquerware, furniture and jewellery. It has been commercially exploited throughout its Indo-Pacific range for at least a century.

In the southern Ryukyus in Japan, divers harvesting sedentary resources have targeted green snail since the 1880s (Yamaguchi, 1988a). As a result of the experience in southern Japan, and more recently, elsewhere, it appears that green snail populations cannot sustain intensive fishing over long periods. This is apparent from the rapid depletion of green snail in actively fished areas and the slow rate at which populations reestablish after the termination of fishing.

The green snail is not an abundant resource in the South Pacific. However, despite its relative scarcity, compared with many other South Pacific marine resources, increasing demand for pearl shell and the relative value of green snail compared with other pearl shell species for inlay work, has resulted in green snail having the premium price. As a result it has made significant contributions to the total value of exports of marine products from several member countries of the FFA in the period since World War II. Until a few years ago, the majority of exports were in the form of complete shells. More recently, in an attempt to add value to exports, it has become increasingly common for the shell to be cut locally to reduce weight and button blanks exported in some cases.

Until recently, relatively little was understood about the biology and ecology of green snail (Yamaguchi, 1988b). With success in rearing other molluscs such as trochus (*Trochus niloticus*) and giant clams (*Tridacna* spp.) in hatchery systems at a number of locations in the Pacific, researchers in Okinawa began aquaria-based investigations on the biology and ecology of green snail in the mid-1980s. As a result, scientists today have a reasonable knowledge of the life history of this mollusc (Yamaguchi, 1988b) although information concerning growth, recruitment and mortality remains poorly documented.

This chapter reviews available information concerning the biology, distribution and ecology of green snail. It includes an overview of the development of fisheries for green snail in the South Pacific and elsewhere and provides information on the volume and value of current exports of this shell from the region. Appropriate research strategies that could be developed to monitor fisheries for green snail in the South Pacific and possible management options that could ensure long term sustainable exploitation of the resource are discussed.

II. BIOLOGY

TAXONOMY

The class Gastropoda is the largest class of the phylum Mollusca. Over 35,000 extant species have been described and to this total should be added some 15,000 fossil forms (Barnes, 1968). The class has an unbroken fossil record since the early Cambrian period and is considered to be at the peak of its evolutionary development (Barnes, 1968).

The green snail, *Turbo marmoratus* (Linnaeus, 1758) belongs to the family Turbinidae in the order Archaeogastropoda, subclass Prosobranchia of the class Gastropoda. Other important members of the family in the tropical South Pacific are *T. setosus* and *T. argyrostomus*.

DISTRIBUTION

The green snail is generally distributed throughout the Indo-Pacific region in the western Indian Ocean (Kenya, Seychelles, Chagos, Andaman and Nicobar Islands throughout southeast Asia (Malaysia, Indonesia, Thailand and the Philippines) to the South Pacific, as far east as Fiji (Cernohorsky, 1973). It has not been reported from Micronesia (Yamaguchi and Kikutani, 1989) and is rare in Australia south of the Torres Strait.

As a result of a successful introduction from Vanuatu in the 1960s, it is now established in French Polynesia (Yen, *pers. comm.*). In the western Pacific its distribution extends to approximately 29° North in the Ryukyu Islands in southern Japan.

HABITAT

Green snail share similar habitats, *i.e.* they are sympatric, with other large gastropods such as the trochiids, *Trochus niloticus* and *Tectus pyramis* and turbinids such as *T. argyrostomus*. Although the degree of overlap among habitats occupied by these gastropods has not been clearly defined, all prefer healthy coral reef environments subject to a constant, good flow of clean oceanic water.

Juveniles are found on reef crests in water from one to five metres deep although adults are found in deeper water. Deeper habitat is characterised by well-developed reef with abundant live coral growth. The topography of the reef crest/seaward reef slope is characterised by elevations, depressions and crevices, having a rich flora of microscopic algae on consolidated limestone substrates or terraces. Green snail range deeper than trochus, extending down reef slopes to at least 20 metres. Throughout their habitat they usually retire during the day beneath coral thickets or into crevices or depressions.

Juvenile green snails smaller than approximately three centimetres shell diameter have not been found in the field. At Tokunoshima in the Ryukyu Islands, large juveniles and subadults have been collected from reef crest areas within crevices made by burrowing sea urchins *Echinometra mathaei* (Yamaguchi, 1988b).

LOCOMOTION

The green snail is nocturnal. It emerges after sunset from crevices and depressions to graze.

The foot of *T. marmoratus* is peculiar in having a central axis along the dorsal central line from the top to the tail of the muscular foot. When moving, either side of the half-foot glides forward and then the other half follows. This alternating movement of the foot is unique in the family Turbinidae.

REPRODUCTION

The green snail is dioecious, *i.e.* the sexes are separate. The single gonad, either ovary or testis, is located in the spirals of the visceral mass next to the digestive gland. Gametes of both sexes are freely released in the water column.

Kikutani (*pers. comm.*) sexed live green snail using its sexual dimorphism in the genital papillae that surround the right kidney opening. Female animals have large bean-shaped papillae while the papillae in males are small and conical. Similar sexual dimorphism in genital papillae is found in *Turbo intercostalis* (Joll, 1980) and *T. argyrostomus* (Tanaka, 1988). The papillae in green snail are visible when the adult snails fully extend their bodies outside their shell.

Devambez (1961) estimated adult green snail in Vanuatu become sexually mature above 15cm shell diameter in Vanuatu. The smallest female snail with well-developed gonads reported from the Ryukyu Islands was approximately 13 cm shell diameter (Yamaguchi, 1988b). Although requiring verification, it is possible that sexual maturity in green snail may be detected by the presence of a continuous rib formed on the upper whorl on the shell of adult snails.

In the Ryukyus, where significant seasonal fluctuations in water temperature exist, green snails appear to breed only in the summer months. Mature specimens are found during much of the warmer period of the year, with peak breeding activity in both early and late summer. It is possible that in tropical areas of their distribution, mature animals breed repeatedly throughout the year.

A female green snail of 2.0 kg (total weight) may contain up to 7 million eggs in a fully-developed ovary. Green snail has not been observed spawning in the wild. In the laboratory, spawning has been induced by a method established for the related species, *Turbo cornutus* (Yamaguchi, 1988b). It was first successfully attempted on green snail in 1986.

Broodstock animals are kept in a holding tank in crowded conditions with strong aeration for one day, by which time the water becomes fouled with excretions and mucus. Within one hour after changing the fouled seawater with fresh running seawater, some of the snails commence spawning, the males first. The spawners must be retained in a dark environment during spawning induction. Due to the copious amounts of sperm produced by males, they should be removed from the holding tank as soon as they begin producing sperm to avoid the possibility of polyspermy of eggs released from the females in the same tank. This method is effective in spawning induction of most larger archaeogastropods, including trochus. Because males are more responsive to induced spawning, the sex ratio of snails should be kept in favour of females in the hatchery production of larvae. Seawater treated by UV-light appears to enhance spawning induction.

Eggs and sperm are ejaculated repeatedly, with contractions of the snail's body into the shell. This activity can last for half an hour. Spawned eggs are slightly heavier than seawater, so that they settle on the bottom of a container if the water is not agitated. However, the eggs can be kept suspended with slight agitation so they are likely to be easily dispersed when spawning occurs in the wild.

EARLY LIFE HISTORY

Knowledge of the early life history of the green snail has resulted from observing the development of fertilised eggs in laboratory conditions following the induction of spawning.

Fertilized eggs of green snail hatch into trochophores about 22 hours after spawning in water temperatures between 21° C and 23° C. This is reduced to 12 hours in water temperatures of 25° C. During the first day after hatching, first the trochophores and later, the veligers swarm near the surface. Pediveligers are formed in the third day and the majority of larvae settle during day four.

Early juvenile green snail show a series of step-wise transformations in shell morphology as they grow (Fig. 1). Just after settling, the first whorl following the transparent protoconch extends with a slight extension of the aperture so that the juvenile appears as a disc with a series of small knobs along the outer corners of the opaque white shell. The juvenile body retains the light green colour of the embryonic stages. Next, the shell aperture expands in the second whorl and two rows of dark brown blotches interspaced with knobs form. By the time the third whorl develops at 3 months, the shell sits relatively flat on the substrate in contrast to the earlier discoid stage which holds the shell upright. Thereafter, the juvenile shell grows spherically. The shell surface gradually becomes uniformly dark green with a series of brown blotches. The juvenile assumes adult-like morphology at about 7 millimetres (mm) shell diameter which is reached about 6 months after fertilisation.

AGE AND GROWTH

Fig. 1 indicates the average growth in shell width of laboratory-raised juveniles. The juveniles probably did not realize their full growth potential during this laboratory exercise to assess growth rates, as the supply of suitable algae was limited. It is likely that juvenile green snail grows to between two and three centimetres in shell diameter one year after spawning.

Judging from the results of field rearing experiments, the estimated age of the green snail at sexual maturity is three to four years (Kikutani, *pers. comm.*).

FEEDING BEHAVIOR

Adult green snail graze on epibenthic microalgae from surfaces of limestone substrates. They also ingest macroalgae. The animal can hold blades of soft algae between the two halves of the frontal part of its foot so that it may pick up and eat algal fronds deposited on the bottom of aquaria.

In the laboratory, green snail prefers green and red algae to brown algae. Among the green algae, *Enteromorpha, Monostroma* and soft varieties of *Ulva* are readily consumed. However, those with a hard texture and consistency, such as *Ulva conglobata*, *U. reticulata*, *Cladophoropsis* spp. and *Dictyosphaeria* spp. are not consumed. Perhaps the most favoured algal genus is *Gelidium* which grows on substrates as short turfs. As long as this genus is available, green snails in aquaria do not select other algae. Red algae favoured include *Gracilaria, Hypnea* and *Eucheuma*, all of which are carageenan- or

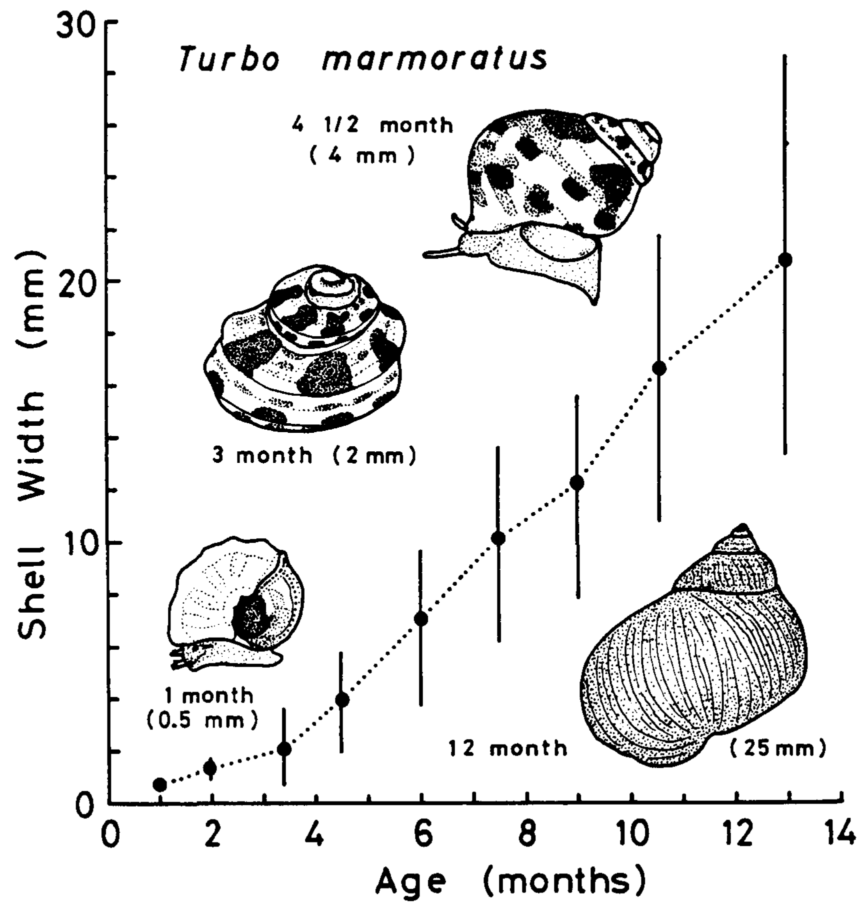

Figure 1. Growth of juvenile *Turbo marmoratus* reared in the laboratory. Note morphological changes as they grew (details in the text).

agar-producing genera in the same category as *Gelidium*. *Dasya* and some other conspicuous species are not accepted as food.

Several species of dried algae, available commercially for human consumption, have also been offered to green snail in the laboratory. All brown algae (*Laminaria*, *Hizikia* and *Undaria*) tested were not consumed and dried *Enteromorpha* did not appear to stimulate the appetite of the snail. Dried *Glacilaria* and *Eucheuma* were consumed, but only in small amounts by starved animals. It is also possible to feed green snail with blocks or films of agar or carageenan jelly originating from commercial agar processed from *Gelidium* or carageenan from *Eucheuma*.

Juveniles can be maintained in laboratory aquaria by feeding with epibenthic microalgae covering coral rubble and other substrates such as plastic plates that have previously been submerged in the sea for several weeks. Feeding substrates in aquaria should be renewed weekly. At about six months of age, juveniles can be fed in laboratory aquaria on fleshy algae such as *Gelidium* and *Monostroma*. During the winter months, when water temperature falls below 18° C, juveniles cease feeding in laboratory aquaria.

PARASITES

Although parasitism and commensalism have not been studied in detail for *T. marmoratus*, some obvious ectoparasites have been recorded as common in field observations of *T. argyrostomus* populations. Yamaguchi and Kikutani (1989) recorded that adult *T. argyrostomus* from Federated States of Micronesia were infested with a number of conical hipponiciid shells, *Sabia* sp. These shells, measuring up to 15 mm at the base, attach around the aperture of the hosts shell where they bore small depressions. Thus if *T. marmoratus* populations are also susceptible to infestations of *Sabia* sp., mortality of juveniles will be significant and the commercial value of adult shell will be adversely affected. Silver-mouth turbans may carry endoparasitic flatworms. Paratized gonads turn to an orange colour instead of being green (female) or cream (male).

PREDATORS

Very small juveniles (less than 1mm in diameter) have been observed to be preyed upon by small acoels which cohabit coral rubble substrates on which veligers settle (Yamaguchi, 1988b). Other small turbellarians, probably a species of *Rhabdocoel*, have also been observed to feed on large numbers of newly settled green snails. Although not tested systematically, there are a large number of potential predators, such as small crabs, predatory gastropods, and others, which could take a large toll on newly settled juvenile green snail.

Juveniles under a few centimeters in diameter (*i.e.* less than one year old), are particularly susceptible to predation. In aquaria, polyclad turbellarians, introduced accidentally with feeding substrates, have been observed to attack and kill juvenile snails by blocking the shell apertures with their flat bodies (Yamaguchi, 1988b). Xanthiid and portunid crabs also attack juveniles by cutting outer shell apertures with their pincers. Some juveniles can survive such attacks by withholding their soft bodies deep inside the shell behind the opercula.

Large hermit crabs frequently occupy green snail shells but whether or not hermit crabs are significant predators requires clarification. Other potential predators of juvenile green snail may be octopii, spiny lobsters, hawksbill turtles, some fishes, such as wrasses and puffer fish, and elasmobranchs such as carpet sharks and rays. Porcupine fishes are probably important predators because their stomachs often contain shell fragments and operculae of gastropods, including turban snails (Yamaguchi, 1988b).

III. FISHERIES AND RESOURCE ENHANCEMENT

FISHERIES

Green snail has been exploited in the Indian and Pacific Oceans and throughout South-east Asia for centuries for the mother-of-pearl trade. However, figures for production are generally inaccurate and highly variable. The Food and Agriculture Organisation of the United Nations (FAO) cites the total world production in 1985 at 500 tonnes (t) [based on Australian and Malaysian figures only]. This increased to 800 t in 1986 and 1,000 t in 1987 and 1988 (FAO, 1990).

Historical catch information is difficult to obtain from areas outside the Pacific. In the Indian Ocean, green snail is harvested in the Andaman and Nicobar Islands where 105 t were harvested in 1976 (Appukuttan, 1977;1979). In the 1940s it was fished commercially in the Seychelles and Chagos Archipelago, fetching up to £400/ton, but, as in other regions, the market declined rapidly with the introduction of plastic substitutes.

In Asia, green snail has been fished commercially in the Philippines since the beginning of this century when fisheries existed in Davao Gulf, off the east coast of Mindanao, at Tawi-Tawi and Sitanki (Seale, 1916). In the 1920s, exports went to the United States of America and Japan (Talavera and Faustine, 1931). In 1979 at least 32 t were collected from the region of Capiz and Zamboanga (Anon., 1980). Indonesia exported an average of 100 t annually mainly to Japan, Singapore and South Korea in the 1960s but exports are now banned. Wells (1989), using data from government custom's statistics, listed major exporting nations of green snail outside the FFA area as follows: Malaysia (400 t in 1980), Andamans (105 t in 1976), Indonesia (77 t in 1981) and the Philippines (32 t in 1978).

In the Pacific, Papua New Guinea, Solomon Islands and Vanuatu have been exporting green snail since World War II. Fig. 2 shows available export figures for the past two decades for Papua New Guinea, Solomon Islands and Vanuatu. The total amount of export from these three countries was 100-200 t per annum in the mid-1970s, but that fell to less than 60 t in the 1980s.

Glucksman and Lindholm (1982) examined developments in the commercial shell industry in Papua New Guinea since World War II and Dalzell and Wright (1986) summarised available information for green snail exports from Papua New Guinea for the period between 1950 and 1984. Wells (1982) reviewed the commercial shell trade in Papua New Guinea, including some discussion on green snail.

During the period 1950-1984, green snail exports averaged 59.7 t per year and contributed 12 percent to the total volume of exports of mother-of-pearl from PNG, the balance being made up of trochus (84 per cent) and pearl oyster (*Pinctada* spp.) shell (Dalzell and Wright, 1986). Current fisheries legislation in Papua New Guinea, the Fisheries Act (1974), prohibits the harvesting of green snail under 15 cm maximum shell diameter. However, as elsewhere in the Pacific, subsistence fishermen diving for sedentary resources do harvest smaller live snails for their meat. The size of such fisheries is unknown.

Annual exports of green snail from Solomon Islands averaged 7.1 t for the period 1981 to 1989 with a range 3.1 t and 22.3 t between years. Skewes (1990) estimated that at recent levels of exploitation, stocks were probably being overfished. Solomon Islands currently has no legislation regulating the harvest of green snail.

The annual production of green snail from Vanuatu was documented during analysis of data relating to the production of trochus in 1983 (Grandperrin and Brouard, 1983). As with trochus, harvest records for green snail from Vanuatu are limited to the period since 1966. For the period between 1966 and 1982, exports of green snail averaged 21 t annually with a range of 7 t to 65 t between years. The Government of Vanuatu has legislated against the harvest of green snail with a shell diameter under 15 cm (Wright, 1989).

Export of unprocessed green snail shell was banned in Vanuatu in 1987 in order to promote value added exports. In early 1990 there were four factories processing green snail in Vanuatu and two in Solomon Islands. The establishment of a factory for processing shell was under consideration in Papua New Guinea.

Although a small portion of the total green snail harvest in the South Pacific is directed to the domestic souvenir trade, the majority of green snail is exported to the commercial button and ornamental trade. Thus, export statistics provide a reasonable estimate of the amount of harvested green snail although with the increasingly common occurrence of exporting cut shell, it is difficult to estimate the weight of shell being processed.

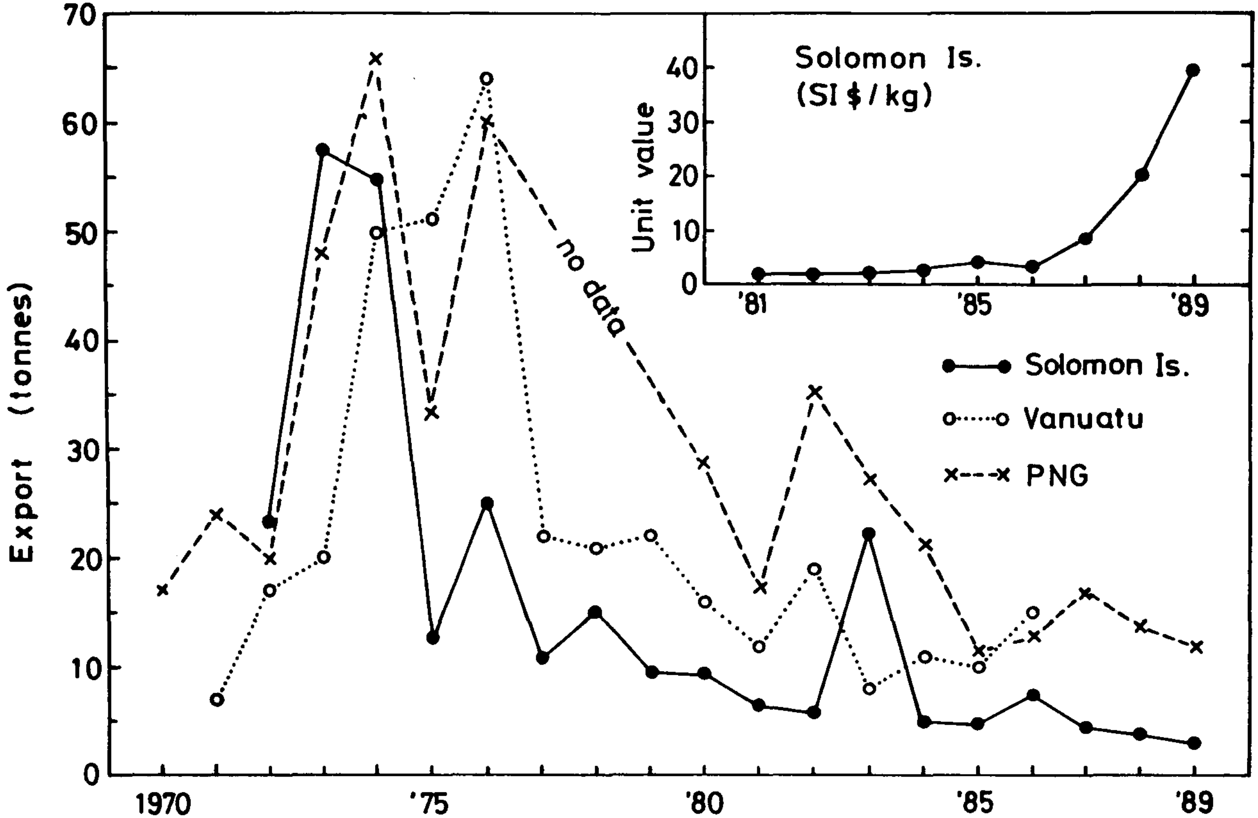

Figure 2. Exports of green snail shell from Solomon Islands, Vanuatu amd Papua New Guinea for the past two decades. Export quantities are not shown for Vanuatu for the years after 1987 because of the export ban on unprocessed shells.

Stocks of green snail in the South Pacific, as elsewhere, are limited. As a result of an increasing shortage of suitable shell for the principal market in South Korea, where the shell is used for inlay work in wooden furniture, prices have increased steeply during the last decade. South Korea imported about 150 t of green snail in 1987 (Philipson, 1989). Fig. 2, depicting the rise in value of green snail exports from Solomon Islands, is indicative of the rapid increase of value of green snail shell in recent years. This is also true for the Ryukyu Islands where the landed price of the shell rose from about ¥1,000/kg to more than ¥4,000/kg during the period 1986 to 1989.

TRANSLOCATIONS

A number of translocations of green snail have been attempted in the South Pacific, one successfully to French Polynesia from Vanuatu (Yen, *pers. comm.*) and one unsuccessfully from Vanuatu to New Caledonia (Gillett, *pers. comm.*). Other countries in the region, for example Federated States of Micronesia (Yamaguchi and Kikutani, 1989) are currently considering the introduction of green snail.

If further translocations are attempted in the South Pacific region in the future, extreme care should be exercised to ensure that organisms other than the target species are not inadvertently introduced at the same time. As with the translocation of *Trochus*, pearl oyster, giant clams and other marine organisms, fisheries administrators and resource managers need to establish suitable protocols for the movement of organisms within the region.

There are a number of potential benefits from the careful introductions or translocations of marine organisms of commercial value in the South Pacific. These include the reintroduction of species to areas in which their populations have become extinct because of over-exploitation and the establishment of commercial resources in areas currently poor in fishery resources. However, extreme care and extensive research concerning mixing of gene pools and the development of rigorous quarantine methodology should precede any movement of organisms in the South Pacific.

IV. RESEARCH

Green snail has not been the subject of any significant research effort in the South Pacific. Virtually all that is currently known about its biology and ecology has resulted from the work of researchers based in Okinawa (Fujimori, 1964; Tanaka, 1988; Yamaguchi, 1988a and b; Yamaguchi and Kikutani, 1989). The results of some of this work relate to the South Pacific.

In the South Pacific, research is required to establish the relationship between adult snail population numbers and recruitment. The relatively short larval life of the snail probably limits the extent to which populations remote from fished areas can supply recruits to active fisheries. If this proves accurate, it is necessary to research the possibility of establishing reserves within areas supporting active fisheries so that snails within the reserve can successfully reproduce.

Therefore, research on green snail in the South Pacific should examine the effects of different levels of fishing intensity on snail populations. In conjunction with this, estimates of the ability of snail populations to re-establish themselves could be addressed. After staff become proficient in locating the snail in its natural habitat and providing that good relations are established with fishermen and processors and that poaching is negligible, a field programme addressing this would be reasonably easy to execute.

Research on the biology and ecology of green snail is probably best left to established marine research institutions as the expertise and funds required to support such work is generally not available in FFA member countries. However, efforts to monitor the developments of research elsewhere should be encouraged. This may lead to hatchery rearing of larvae and the enhancement of natural populations. However, experience with other gastropods, such as trochus, suggest that applied research still has some way to go before the benefit of this approach can be evaluated.

Although not research *per se,* a priority among South Pacific countries is the development of a proper information system to monitor resource exploitation, to establish guidelines for green snail harvests and to provide a basis for necessary legislature. Effective research strategies that will provide information for monitoring and efficiently managing fisheries for green snail in the region are required. This also applies to other sedentary fisheries resources such as trochus and bêche-de-mer and as a result, developments in fisheries management for those resources may be applied to green snail.

Few FFA member countries, Fiji possibly being an exception, are addressing current deficiencies in recording the volume and value of exports of marine produce (Wright, 1990). This requires the establishment of a coordinated programme between customs departments, taxation offices and fisheries administrations. A concerted effort to record accurately all exports of marine produce will not only provide information useful for the development and management of fisheries in each country but also may result in an increase in revenue for the country as exporters are encouraged to report more accurately.

V. RESOURCE MANAGEMENT AND CONSERVATION

With a rapid increase in the value of green snail shell, an increase in fishing pressure on stocks of green snail has resulted. In many areas, this has probably led to a substantial reduction in snail populations throughout its distribution. Although in some regions such as the Ryukyu Islands, the general availability of self-contained underwater breathing apparatus (SCUBA) and hooker may have contributed to this demise, the majority of the harvest is still taken without this assistance throughout the Pacific. As snail is found beyond free diving depths in the region, the potential for deep water individuals to continue to supply recruits to shallow water areas remains. However, should harvesting with SCUBA become widespread in the region, this conservative mechanism would be removed and the green snail resource could thus become more threatened.

Even when the snails were harvested by divers without diving apparatus, the stock in the Ryukyu Islands tended to be over-exploited (Fujimori, 1964). In that region there were previously many diver-fishermen who harvested a number of sedentary resources including green snail, by freediving. Many of these fishermen have retired, mostly without successors, because local green snail stocks have been so reduced they can no longer support such fishing.

In order to protect green snail resources and to increase the possibilities of long-term sustainable exploitation, FFA member countries need urgently to assess current fishing, processing and export legislation. This could involve the introduction of minimum and maximum size limits and the establishment of reserves to protect brood stock.

A minimum size limit would reduce the possibility of growth overfishing. The introduction of a maximum size limit is attractive because large shells tend to be damaged due to worm infestations, thus are of a negligible commercial value. In addition, larger individuals are more fecund.

If the relatively short larval life of the green snail restricts the distribution of larvae over a wide area, recruitment to any over-exploited area from stocks located a large distance away might not be expected to occur. Detailed consideration of the spacing of reserve areas adjacent to green snail fisheries, that are preferably accurately monitored, could include an experimental arrangement of reserves spaced at varying distances.

In Okinawa, fishermen are prohibited from harvesting live shell less than 6 cm in shell aperture diameter. This size corresponds with about 13 cm in shell width, and is close to the size of first maturity. Therefore, this regulation, as a means of ensuring adult snail mature to reproduce and supply new recruits to the fishery, is inadequate.

However, because the growth rate of young adults is not known, it is difficult to estimate a more reasonable size limit based on the reproductive efficiency of the animal. The size limit for harvesting green snail in Vanuatu (15 cm shell width) is also of questionable value.

Hatchery production of juvenile green snail is now established at the Okinawa Sea-Farming Center. Techniques involving juvenile release for reef-ranching of green snail are being developed using hatchery-produced juveniles. Provided hatchery reared juveniles can successfully establish themselves on reefs once released and provided the coral reef ecosystem can support the release of a large number of juvenile green snail without disrupting the general ecological status of the reef, there is some hope that commercial green snail fisheries can be maintained or even enhanced. In addition, these developments also offer potential for the introduction of commercially valuable resources to areas with few cash generating opportunities.

VI. ACKNOWLEDGEMENTS

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