Spiny lobster ecology and exploitation in the South China Sea region

Proceedings of a workshop held at the Institute of Oceanography, Nha Trang, Vietnam, July 2004

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Cover photo shows a market-size tropical spiny lobster (*Panulirus ornatus*) and aspects of lobster culture in Viet Nam. Photos by staff of Institute of Ocenography, University of Fisheries and CSIRO Marine Research.

Foreword

TROPICAL spiny lobsters, and particularly the ornate lobster *Panulirus ornatus*, are a very valuable resource for most countries bordering the South China Sea. Because of their high market value, lobsters are under severe fishing pressure and this level of exploitation is a serious threat to the sustainability of the stocks. Both as a means of adding value to the existing fishery and in response to the greater catch effort required to fish wild lobsters, lobster farming has developed since the mid-1990s into a US$50–60 million per annum industry for Vietnam. The industry is totally reliant on the collection of settling wild seed lobsters, with these then being on-grown to a marketable size in 15 to 18 months. Herein lies the dilemma: if the harvesting of these seed lobsters critically damages natural recruitment processes, then it will only be a matter of time — a very short time most likely — before the adult stocks are decimated and the fishery and aquaculture industries are no more. Timely and effective management of the common lobster resource is an urgent priority to sustain the wild lobster population and the prosperity that flows to the region from this resource.

This workshop brought together oceanographers, lobster biologists and lobster aquaculture researchers with an interest in the sustainability of the South China Sea spiny lobster stocks. Its purpose was to provide an exchange forum to discuss what is known about the ecology of tropical spiny lobsters, particularly *P. ornatus*, and the oceanographic factors that influence the transport and distribution of their larvae. A second objective was to identify knowledge gaps presently limiting assessment of the impact existing fishery and aquaculture practices have on the sustainability of lobster stocks in the South China Sea.

The presentations and discussions emanating from the workshop are reported here. The next step will be to engage regional governments and other agencies so that appropriate, effective and enforceable management polices are developed to sustain the spiny lobster population in the South China Sea for the benefit of all countries.

Peter Core
Director
Australian Centre for International Agricultural Research

Contents

Executive Summary

The Australian Centre for International Agricultural Research (ACIAR) sponsored a two day workshop at the Institute of Oceanography, Nha Trang, Vietnam to discuss the sustainability of the tropical spiny lobster fishing and aquaculture industries in the South China Sea region. The workshop was held on 20–21 July 2004. It provided a scientific forum for information exchange on the use being made of the lobster resource in the region and the measures that should be taken for sustainable exploitation of the lobster stocks in the region. The workshop was attended by 30 invited participants, with papers presented by 11 keynote speakers from Australia, Malaysia, the Philippines and Vietnam. Topics covered included: the status of the spiny lobster resource and its exploitation in each country, fishery-independent methods for assessment of lobster stocks; oceanographic features of the South China Sea and how these features might influence regional ecology of the lobsters, and larval dispersal prediction models for determining the source of the lobster seed settling along the coastline of Vietnam and the Philippines.

While data on the level of exploitation of the lobster fishery were almost non-existent or confounded by the importation and re-export of lobsters between countries — including Indonesia — the heavy fishing pressure being exerted on the lobster stocks was apparent with increased catch per unit effort (CPUE) and reduction in the average size of fished lobsters. The magnitude of lobster seed exploitation for aquaculture grow-out in Vietnam was quite remarkable. The number of harvested lobster seed has increased exponentially every year since the mid-1990s when lobster aquaculture first began in Vietnam, with an estimated 3.5 million seed taken in 2003 for aquaculture ongrowing. In the same year, Vietnam's production of cultured lobsters was estimated to be 2000 metric tonnes, and worth US$60 million. There is similar, but as yet smaller-scale, lobster aquaculture development in the Philippines and Sabah.

Annual monsoonal events result in large outflows of freshwater and sediment from the Red River in the north and the Mekong River in the south with these having severe impacts on the coastal and adjacent waters of the South China Sea. Two main geotrophic eddies are recognised in the South China Sea: a clockwise-flowing cyclonic current in the north-western and northern parts, and an anticlockwise-flowing current in the central and south-western parts, with diverged and converged zones where these opposing currents meet. The current speed is typically stronger in the summer than in the winter. Along the continental shelf of Vietnam there is a strong southward moving cold current that exists all-year round. There is also a northward moving warm current, which flows at greater velocity during the summer. These opposing currents result in strong upwellings, which occur seasonally up and down the continental shelf region of southern central Vietnam. These upwellings play an important role in the ecosystem, biodiversity, resources and oceanographic dynamics of the region.

Modelling of the transport processes affecting the distribution of lobster phyllosoma during their oceanic larval development period of five to eight months is still at its infancy. In the absence of robust data on the regional location and abundance of spawning stock and detailed knowledge on the type and availability of food needed by the phyllosoma and the natural rate of predation they suffer during larval development, transport modelling is a best estimate only. Early modelling based on known oceanographic and biological processes suggest that lobster seed settling along the central coast of Vietnam most likely originates from spawnings in northern Philippines. However, other sites, including as far south as Sabah could not be excluded. Further refinement of the models and some form of ground truthing of the prediction are high research priorities. A genetic population study of the lobsters in the South China Sea might assist in establishing the origin of settling seed. However the long larval development period and the potential for mixing of the phyllosoma in the eddies of the South China Sea mitigate against the likelihood of genetically distinct lobster populations occurring in the region.

There was unanimous agreement for a collaborative, region-wide, approach to address knowledge gaps that presently limit a sound assessment being made of the sustainability of the tropical spiny lobster resource of the South China Sea. Identified research needs and the suggested approach were:

1. Source and sustainability of lobster seed supply

1.1 Improve, expand and validate larval transport model. Assess likelihood of *P. ornatus* population genetic study revealing origin of settled seed. Use best combination of methods to locate source of lobster seed supply.

1.2 Spatial and temporal census of harvested lobster seed and CPUE (including some fishery-independent sampling).
1.3 Fine-scale modeling of likely success of larval development of phyllosoma hatching naturally from cultured lobsters (at culture site or relocated release site).
1.4 Spatial and temporal survey of the physiological condition of developing phyllosoma and identification of natural food abundance (signature lipid analyses of phyllosoma and associated plankton).
1.5 Evaluate merit of imposing either minimum or maximum sizes on lobster seed harvested for aquaculture grow-out (relative mortalities of wild and cultured seed).

2. Abundance of spawning *P. ornatus* lobster stock

2.1 Annual survey of abundance and size-class of lobsters at prime spawning sites and tag and re-capture studies to assess behaviour (once the location of spawners has been identified from 1.1 above).
2.2 Implement catch data collection at landing ports and along market chain to identify lobster resource use in region

3. Minimise environmental impacts of lobster aquaculture

3.1 Determine environmental impact of present lobster farming practices (desk audit of nutrient flows and pathways) and impacts of eutrophication from other industries (babylon snail and shrimp culture) and activities in the coastal zone.
3.2 Determine optimal (sustainable) carrying capacity for lobster culture sites and examine whole sustainability of the whole system, including human health concerns of bio-accumulation of harmful agents with co-culture practices (mussel culture).
3.3 Improve feed delivery and develop eco-friendly feeds to reduce nutrient release from lobster culture cages and impacts on other fisheries.

It was recognised that region-wide, systematic tackling of the above issues will require substantial funding. However, unless such research is implemented, there are grave concerns for the sustainability of the tropical spiny lobster resources of the South China Sea and the collapse of the lobster aquaculture industry.

Session I
EXPLOITATION OF THE WILD TROPICAL SPINY LOBSTER RESOURCE OF THE SOUTH CHINA SEA

University of Philippines, Marine Science Institute

Most lobsters in Western Mindanao are caught by compressor (hookah) divers. Fishers go out in teams of two or more divers per boat, where divers spend an average of 2–7 hours during fishing operations.

Status of Spiny Lobster Resources of the Philippines

Marie Antonette Juinio-Menez and Rachel R Gotanco

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Introduction

SPINY lobsters are among the most highly prized and threatened invertebrate fishery resources in the country. Information on lobster biology, fisheries and management (including grow-out culture) were derived from a nationwide questionnaire survey (of fishers, local buyers, traders and national and local government agencies) in 1994–1995, site visits in selected lobster fishing areas and various publications and studies on local spiny lobsters (Juinio-Meñez and Dantis 1996).

Species distribution and relative abundance

There are seven species and subspecies of *Panulirus* reported in Philippine waters (Fig. 1). Of these the most widely distributed are *P. ornatus, P. versicolor* and *P. penicillatus.* Three species of morphologically similar lobsters (*P. longipes longipes*, *P. longipes bispinosus* and *P. femoristriga*) are also widely distributed. Preliminary surveys, however, indicate a differential distribution of *P. l. longipes* and *P. l. bispinosus,* with each subspecies predominant in the western and eastern Philippine coast, respectively (unpublished

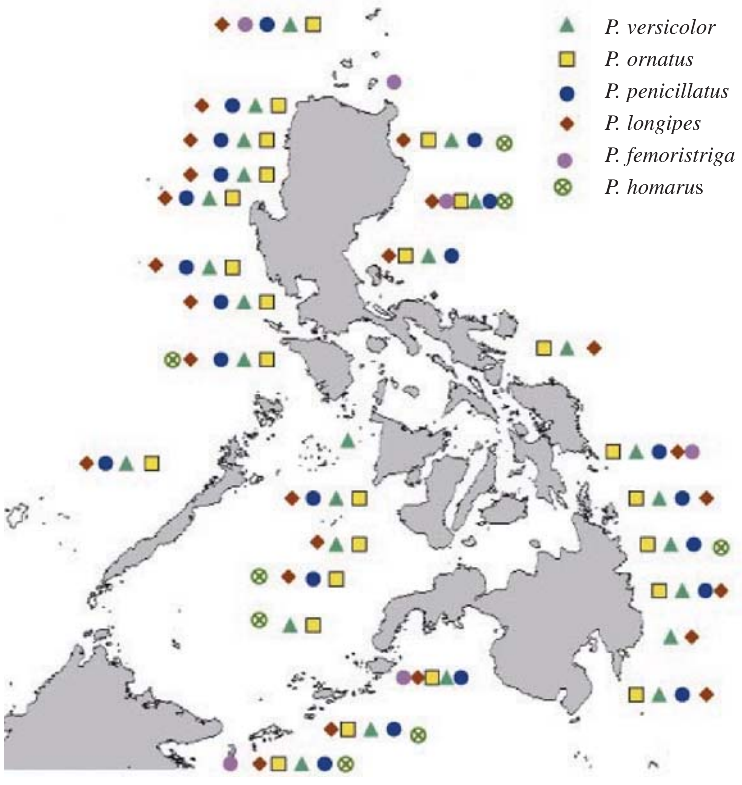

Figure 1. Species composition and distribution of commercially exploited lobster species at various localities.

data). However, with the recent taxonomic revisions in this group, i.e. recognition of *P. femoristriga* as a distinct species (Chan and Ng 2001, Ravago and Juinio-Meñez 2002), the distribution and relative abundance of these cryptic species and subspecies need to be re-examined. Finally, *P. homarus* appears to be the least commonly observed.

The reported relative abundance of the different species varies considerably across different localities and times of the year (Fig. 2). This is in part due to differences in available suitable habitats and fishing activities as affected by monsoon seasons. The variability in the seasonality of reported incidences of egg-bearing females and juvenile lobsters provide some insights into the recruitment dynamics of lobster populations in different localities in the country. Egg-bearing females for the most common species have been reported year round across different areas. In general, the predominant egg-bearing season reported for most localities was during the summer period from April to May and the least being during the colder periods of November to February. However, in Palawan and western Visayas, southwestern and southern Mindanao, higher incidences of egg-bearing lobsters were noted during the colder months.

Spiny Lobster Fishery

Various types of fishing gears/methods are used for catching lobsters in different provinces. Lobsters are most often caught with the use of native spear guns, hookah diving with compressor and gill nets and are incidental catches in fish corrals, hook and line, and crab pots (Juinio-Meñez and Dantis 1996). The reported catch per unit effort varied widely among gears and localities. The highest daily catches reported were 50 kg per fisher per day in Batanes, Aurora, Davao Oriental and Sulu. Notably in some localities where there is no marked monsoonal season, such as in southern Mindanao, a peak season for catching lobsters was reported from March to August. This suggested that other factors such as natural seasonality in lobster abundance (for example, due to migratory or reproductive behavior) determine lobster availability in a particular locality. Fishers sell their catch to local buyers who are financed by large

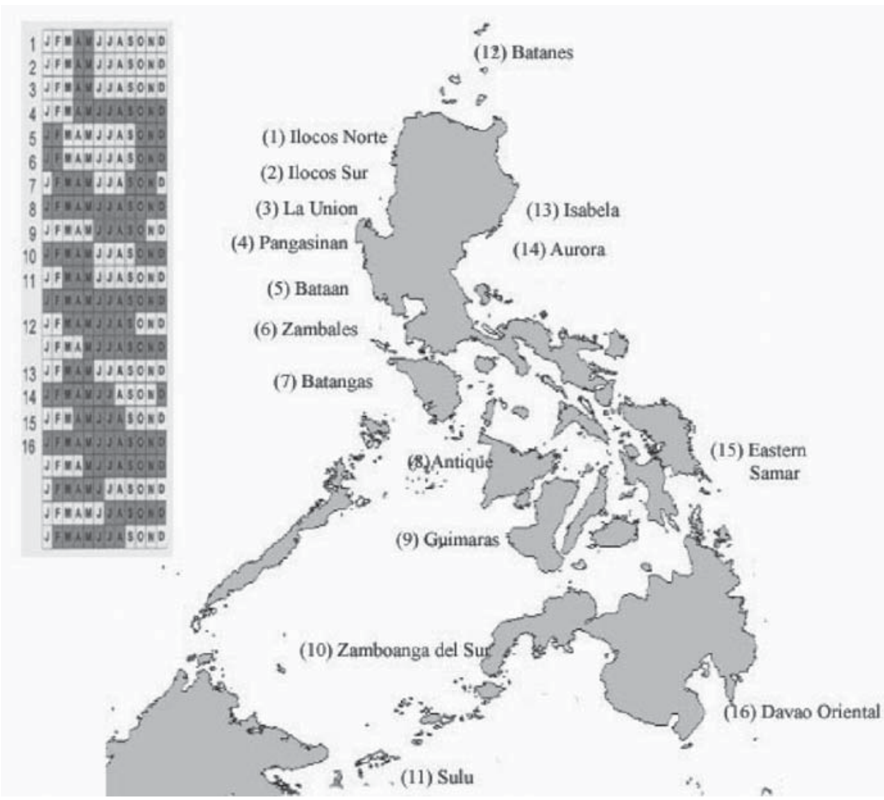

Figure 2. The time of year when specific lobster species are most abundant at various localities.

marine products trading companies that have buying stations nationwide. These traders pass on the products (live or processed — frozen/iced whole animals or tails only) in the local market or to exporters, or they export them directly. The most expensive products are live lobsters (i.e. for *P. ornatus* and *P. versicolor*), which fetch at least PHP1500.00 ($US 27.00) per kg. in the local markets. Results of the questionnaire survey and account of various fishers and traders nationwide clearly indicate decimation of many local populations. Consistently, a significant decrease in catch per unit effort and size of all kinds of lobsters caught has been reported since the late 1980s. In 1979, the spiny lobster catch was reported at 1457 MT but has since shown a steady decline with only 269 MT reported in 2001 (FAO Fishery Statistics FIGIS; see Fig. 3). Of late, interviews with fishers indicate that lobsters are now rarely caught in some places in Central Visayas where they used to abound (for example, Bohol). Unfortunately, very few municipalities have fishery ordinances and or implement any management measures for lobsters, as is the case for other marine invertebrate fishery resources in the country.

Spiny Lobster Resource Management

Grow-out initiatives

Initiatives to 'farm' or 'culture' spiny lobsters in the country date back to the 1970s with the establishment in some areas of experimental lobster farms by the Bureau of Fisheries and Aquatic Resources (BFAR). The most significant effort that is sustained to date is the pilot lobster farm in Guiuan, Eastern Samar. In this farm early juvenile *P. ornatus* were collected from fish corrals or from crevices in reef areas (for example, *P. longipes, P. versicolor*) and reared in experimental floating cages and pens. Valuable information on growth and the reproductive biology of some species were derived from monitoring studies for captive lobsters since lobsters in the farm attained sexual maturity and mated in captivity (Juinio-Meñez and Estrella 1995). In the early 1990s, BFAR region IX promoted lobster culture to families of fishers in Basilan, Western Mindanao. Local residents constructed enclosures underneath their stilt houses to rear lobsters to marketable size, which were sold to exporters in Zamboanga. Likewise, interest in lobster grow-out by the private sector peaked in the late 1980s to the early 1990s following trends in Taiwan. Interest in this 'new technology' brought about a significant shift in the local fisheries from spear fishing to the use of compressors (and in some cases together with cyanide) to harvest live lobsters, particularly juveniles (<150 g) for export to Taiwan for grow-out culture operations.

Prior to the lifting of the ban to export live lobster juveniles in February 1992, local exporting firms sent shipments of juveniles to Taiwan declared as 'aquarium products'. After the ban was lifted volumes of juvenile exports increased and then declined drastically. Initially the decline in export was brought about by the growing demand for live juveniles in the local market as local aquaculture firms ventured into lobster culture. Pond lobster grow-out culture was tried by some aquaculture companies to diversify their products and optimise existing facilities in the advent of the decline in the local prawn industry. However, the supply for juvenile lobsters became scarce such that, in 1993, major aquaculture firms

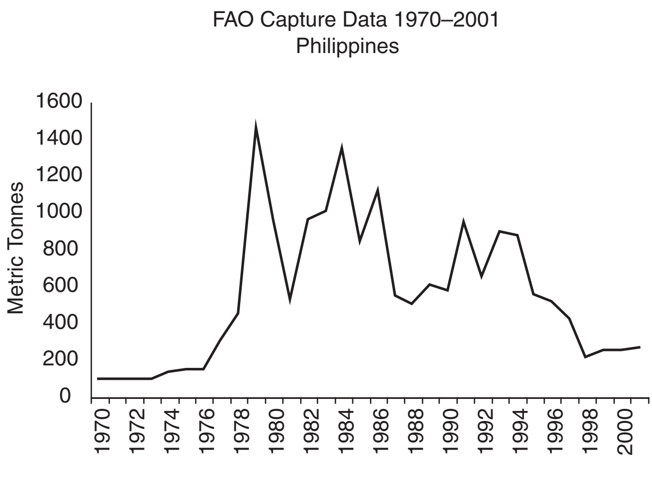

Figure 3. Capture data (MT) from 1970 to 2001 based on statistics from FAO.

began to import lobster juveniles from Indonesia and Malaysia to augment local supply. Likewise, the supply of lobster juveniles in the Basilan area dwindled and larger scale grow-out culture was not viable. Overall, the harvesting of juveniles for grow-out culture has contributed to the further decimation of local lobster populations.

Future Directions

THE shift to a live lobster fishery in theory provides opportunities for selective harvesting (for example, size limits, release egg-bearing lobsters) which was not possible in the case of the traditional spear fishery. However, it is impossible to expect fishers to release egg-bearing females. Workable mechanisms to help the recovery of lobster populations remain a formidable challenge. The establishment of 'reproductive' reserves and strict implementation of size/gear regulations is clearly needed. However the cooperation of lobster traders, fishers and the local government is imperative for this to be implemented. In addition, research that will provide additional insights on lobster recruitment dynamics will be useful in identifying appropriate areas for protection or enhancement on the one hand, and more sustainable sources of early juveniles/pueruli on the other hand.

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Status of Spiny Lobster Resources in Sabah, Malaysia

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Introduction

SPINY lobsters (*Panulirus* species) make up an important component of the niche live reef fish trade (LRFT) markets of Hong Kong, Taiwan and Singapore. In 2001, exports of spiny lobsters in various forms (live, fresh, chilled and frozen) amounted to around 97 MT (US$1.37 million), representing some 0.1% by volume and 0.6% by value of Malaysia's total fish exports (Table 1).

Fishing grounds

Sabah accounts for most of the annual live spiny lobster exports. The purpose of this paper is to give an overview of the present status of spiny lobster resource exploitation in the country with a special reference to the state of Sabah — on the northern tip of Borneo Island (Fig. 1).

The main spiny lobster fishing grounds in Malaysia are based in Sabah, which account for 75% of the coral reefs in the country. In the neighbouring state of Sarawak, there are only a few coral reefs limited to the Tanjung Datu and Talang-Satang Group of Islands, and areas off the shores of Bintulu and Miri. According to some local fish traders, the reef shoals off Miri account for some of the spiny lobsters being exported via the federal territory of Labuan. Peninsular Malaysia accounted for less than 20% of the coral reefs in the country. However, most of the coral reef areas including small offshore islands have been gazetted either as marine parks under the *Malaysian Fisheries Act 1985* or zoned for ecotourism and hotel resorts, where fishing of any kind is totally banned or strictly controlled. Some spiny lobster landings were reported in Johore and Singapore, but no landing statistics were available for the purpose of this paper.

Excluding Sabah, a total of 40 areas have been gazetted under the *Malaysian Fisheries Act 1985* as marine parks in the country. In Sabah, the management of marine parks falls under the state government jurisdiction, where marine parks are gazetted under the state ordinances or enactments. Sabah has four gazetted marine protected areas, with three being managed by Sabah Parks — Tunku Abdul Rahman Park and Pulau Tiga Park on the west coast and the Selingan Turtle Islands on the northeast. On the other

Table 1. Spiny lobster export and import statistics, Malaysia (FAO, 2004).

Year	Exports		Sabah exports[1]	Imports		Re-exports	
	Q	V		Q	V	Q	V
1990	61	349	43	62	232	—	—
1991	106	623	99	30	338	—	—
1992	143	1194	133	259	906	—	—
1993	144	1295	114	73	1385	—	—
1994	193	1388	72	82	832	—	—
1995	66	1553	70	58	996	—	—
1996*	91	2042	77	533	2056	—	—
1997	134	2123	66	107	2118	—	—
1998	122	1951	70	76	1010	45	293
1999	91	1629	81	105	1292	64	283
2000	121	1838	85	86	1737	38	248
2001	97	1372	58	151	2218	58	167

Q — quantity (metric tonne); V — value (US$ '000). In live, fresh, chilled and frozen forms; Exports from Sabah in live forms only.
[1]DOF Sabah annual fisheries statistics (data reported by the Royal Customs and Excise Department of Malaysia).
*Discrepancies for 1996 were due to trade statistics being obtained from two different data sources.

Figure 1. Location map of Sabah (east Malaysia) and peninsular Malaysia.

hand, the Sugut Islands Marine Conservation Area near the Selingan Turtle Islands is managed by Sabah Wildlife Department. Another two MPAs are now in the pipeline to be gazetted — Tun Sakaran Marine Park in Semporna and Tun Mustapha Park in Kudat.

The major spiny lobster fishing grounds in Sabah are concentrated around coastal islands and offshore shoals that have extensive fringing coral reefs. These waters are relatively shallow with average depths ranging between 5–10 fathoms. Among the important fishing grounds are the Darvel Bay (Tawau–Semporna) and Tambisan Island on the east coast, Banggi group of islands and Malawali Island in the north, and Mantanani group of islands and Pulau Tiga group of islands along the west coast (Fig. 2). Besides spiny lobsters, these areas are also important sources of groupers and other high value reef fishes targeted for the LRFT fishery based in Hong Kong.

Assessment of Spiny Lobster Resources

In the 1970s, DOF Sabah conducted a series of surveys on the distribution of spiny lobsters in Sabah through experimental fishing using various kinds of gears.

Figure 2. Main spiny lobster fishing grounds in Sabah, Malaysia (circled).

Since then, no further assessment had been carried out. Some biological data for *P. ornatus* cultured in marine cages was carried out in 1997 (Azhar 1999) and is shown in Table 2.

Spiny Lobster Fishery

The potential of spiny lobsters in Sabah as a commercial species was first realised in the late 1960s, and throughout the 1970s DOF Sabah conducted a number of surveys on the species distribution including experimental fishing. However it was not until the late 1980s that spiny lobsters became a commercially targeted species. In 1988 the first significant commercial attempt was carried out by a fishing company with Korean interests. The company planned to export the catches in cooked headless form. Fishing was carried out using baited pots from a 300 GRT vessel. Persistent poor catches forced the company to resort to other fishing methods including night diving and the use of trammel nets. However, the company ceased operation after two years.

In 1989 another company experimented with exporting lobster live to Hong Kong by air. Because of the attractive prices being offered in Hong Kong, since 1991 the number of companies involved in spiny lobsters has proliferated. Fishing methods employed include night hand-collecting and the use of trammel nets. A typical spiny lobster boat is relatively small — less than 10 GRT — and powered by 30–75 HP inboard engines. It would normally have five to six crew members with three to four divers. The divers would dive in tandem over the reef area with air supplied from the boat through a compressor via flexible hoses fishing areas. The catches were brought up and kept in specially constructed live wells inside the boat. The catches were either kept on land in cement tanks or in marine cages prior to export. Since 1996, reliable sources within the trade have indicated that spiny lobster catchers have resorted to using sodium cyanide to catch lobsters during the day. In order to command high prices, mild doses are used to ensure that the catches are not damaged. Some traders believe that more than 50% of the spiny lobsters landed are caught by cyanide fishing. There are no data available on the number of operators or fishing vessels involved in the spiny lobster fishery

There are five *Panulirus* species being exploited in Sabah waters, with *P. longipes* being the most common species, followed by *P. versicolor, P. ornatus* and another two unidentified species. *P. ornatus* is the most sought after species among fish traders, fetching an average of RM70/kg wholesale on the local market and an export price of RM115/kg wholesale in Hong Kong. *P. versicolor* is the next highest price species (RM50/kg wholesale; RM80/kg export) followed by *P. longipes* (RM45/kg wholesale; RM75/kg export). The price of the other two unidentified species are reported to be much lower compared with the aforementioned three species. Spiny lobsters represent an important component of the marine cage culture production in Sabah. Exporters or farmers normally reared them in cement tanks or sea cages prior to export or harvesting. The culture period depends on the timing of the next export shipment or when fish traders (middlemen or exporters) come to the farms to buy their products.

According to available statistics, landings of spiny lobster in Sabah have increased from 30 MT in 1996 to 80 MT in 2002 (Table 3). Tawau and Semporna account for 53% of the 2002 landings, with supplies coming from the Darvel Bay as well as other landings from Indonesia (Manado) via Tarakan and from the Philippines (Sitangkai) via Semporna. Kudat accounted for 45% of the 2002 landings, with supplies from the Banggi group of islands and Sandakan waters as well as from the Philippines (Palawan). The spiny lobster landings in Kudat fluctuated throughout the years due to the inconsistent supplies from the Philippines. On the other hand, spiny lobster landings in Kota Kinabalu were small, accounting for only 2% of the 2002 landings. There were several reasons for this, with most catches landed in the federal territory of Labuan (unrecorded), as well as declining catches due to the gradual destruction of habitats in coral reef areas by blast fishing practices.

Table 2. Biological data of *P. ornatus* cultured in marine cages, Darvel Bay, Sabah.

Sex	n	CL range	TL range	BW range	Length weight relationship
M	51		136–343	118–1900	–8.7010 + 2.7388 Ln TL (r2 = 0.9824)
F	52		113–420	58–2270	–9.0475 + 2.7936 Ln TL (r2 = 0.9810)
M	103	45–139		84–2220	–6.3373 + 2.8466 Ln CL (r2 = 0.9839)
F	93	21–140		21–2520	–6.6636 + 2.9304 Ln CL (r2 = 0.9332)

CL — carapace length (mm); TL — total length (mm); BW — body weight (g).
Minimum size at maturity: Male — 98 mm CL; Female — 107 mm CL.
Source: Azhar Kassim 1999. Preliminary studies on the maturity size and growth rate after moult of *Panulirus ornatus*. B.Sc. thesis. Universiti Putra Malaysia. 87p.

Table 3. Spiny lobster landings in Sabah, Malaysia (MT).

Year	Main Landing Districts				Total landings	Annual exports
	A	B	C	D		
1996	2.15	8.86	16.75	1.99	29.75	77.60
1997	6.27	11.19	13.17	7.01	37.64	67.12
1998	13.42	11.02	13.99	10.26	48.69	73.53
1999	11.94	11.14	8.45	1.57	33.10	82.76
2000	31.18	11.43	6.64	2.67	51.92	86.60
2001	31.64	16.53	4.41	2.72	55.30	60.20
2002	25.87	16.44	35.74	1.84	79.89	46.62
Total	122.47	86.61	99.15	28.06	336.29	494.43

A — Tawau; B — Semporna; C — Kudat; D — Kota Kinabalu (including Kota Belud).
Source: Department of Fisheries Sabah annual fisheries statistics.

Spiny Lobster Trade

Spiny lobsters traded out of Sabah are mainly exported live, with most of the consignments destined for the LRFT markets in Hong Kong and Taiwan (Figs. 3–5). According to statistics obtained from the Royal Customs and Excise Department, exports of spiny lobsters increased from 43 MT in 1990 to 133 MT in 1992, and then declined gradually to only 47 MT in 2002. The export data of spiny lobsters by destination for the 1990–2002 period is given in Table 4. The decline in export volume was due to the annual export quota of 70 MT enforced by DOF Sabah since 1994.

Table 4. Destination and volume (quantity and value) of live lobsters exported from Sabah, Malaysia.

	Destination of live lobsters							
Year	China	Brueni	Hong Kong	Japan	Singapore	Taiwan	Domestic	Total
	Quantity (metric tonne)							
1990	0.0	0.2	35.2	0.1	7.6	0.0	0.1	43.1
1991	0.0	0.1	83.1	0.9	12.0	2.6	4.2	102.8
1992	0.0	0.3	127.9	0.0	4.6	0.0	0.4	133.1
1993	0.0	0.3	109.3	0.0	4.5	0.0	0.0	114.1
1994	0.0	0.0	63.7	0.0	8.3	0.2	0.0	72.2
1995	0.0	0.0	46.6	0.0	0.6	23.2	0.0	70.3
1996	0.1	0.3	53.1	4.3	0.0	19.6	0.3	77.6
1997	0.0	0.1	50.4	0.0	0.1	15.7	0.8	67.1
1998	0.9	0.0	61.7	0.0	1.9	6.9	2.1	73.5
1999	0.0	0.0	49.5	0.0	4.6	27.3	1.4	82.8
2000	0.0	0.0	55.9	0.3	7.0	21.5	1.9	86.6
2001	0.0	0.0	46.1	0.0	1.8	10.0	2.3	60.2
2002	0.0	0.2	32.0	0.0	1.3	12.2	1.0	46.6
	Value (RM million)							
1990	0.0	0.01	0.68	<0.01	0.09	0.00	<0.01	0.78
1991	0.0	<0.01	1.38	0.01	0.19	0.05	0.09	1.71
1992	0.0	0.01	2.80	0.00	0.12	0.00	0.01	2.93
1993	0.00	0.01	2.81	0.00	0.17	0.00	0.00	2.98
1994	0.00	0.00	2.33	0.00	0.47	0.02	0.00	2.81
1995	0.00	0.00	2.44	0.00	0.02	1.55	0.00	4.00
1996	0.01	<0.01	3.25	0.25	0.00	1.55	0.02	5.08
1997	0.00	<0.01	3.45	0.00	<0.01	0.98	0.07	4.51
1998	0.07	0.00	4.67	0.00	0.14	0.55	0.12	5.55
1999	0.00	0.00	3.84	0.00	0.29	2.20	0.09	6.42
2000	0.00	0.00	4.30	0.02	0.44	1.64	0.21	6.61
2001	0.00	0.00	3.59	0.00	0.12	0.84	0.16	4.71
2002	0.00	0.01	2.58	0.00	0.06	0.98	0.07	3.70

The export data include spiny lobsters brought in from neighbouring countries. Previously there was a steady supply coming from Palawan Island in the Philippines through Kudat, but in recent years the volume has declined due to much better prices being offered by fish traders in Manila. Supplies from Manado, Indonesia and Sitangkai–Southern Philippines were brought in respectively via Tawau and Semporna. However, no official documentation is available on the actual volume of spiny lobsters being 'imported' from these two countries. Supplies from Manado comprised mainly the highly valued *P. ornatus*, while supplies from Sitangkai comprised a combination of *P. ornatus, P. versicolor, P. longipes* and other species.

Fishery Management

Fishing activities in Malaysia, including spiny lobster exploitation, are enforced by DOF Sabah under the *Fisheries Act 1985*. DOF Sabah is preparing the final draft of a spiny lobster fishery management policy for Sabah. It will specify:

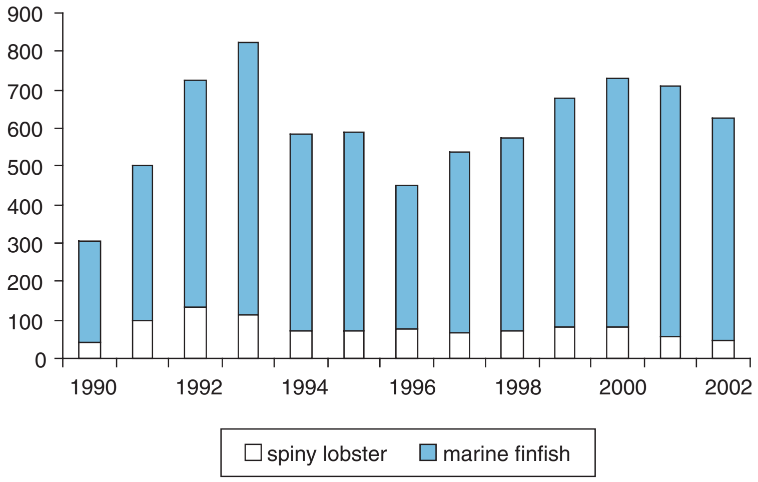

Figure 3. Annual exports of live products, Sabah, Malaysia (MT).

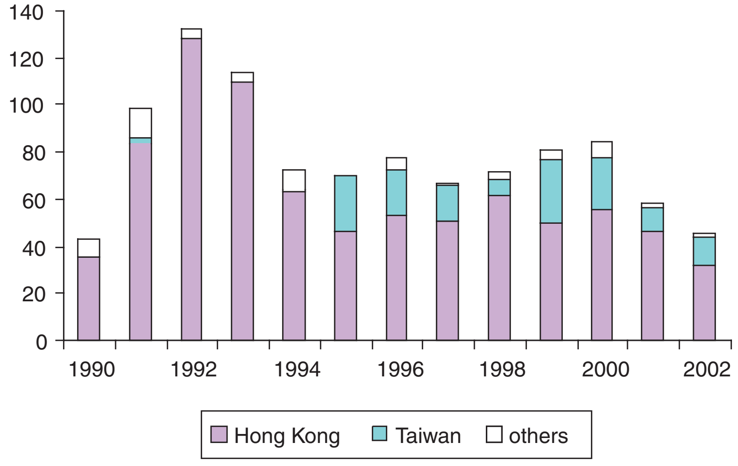

Figure 4. Annual spiny lobster exports, Sabah, Malaysia (MT).

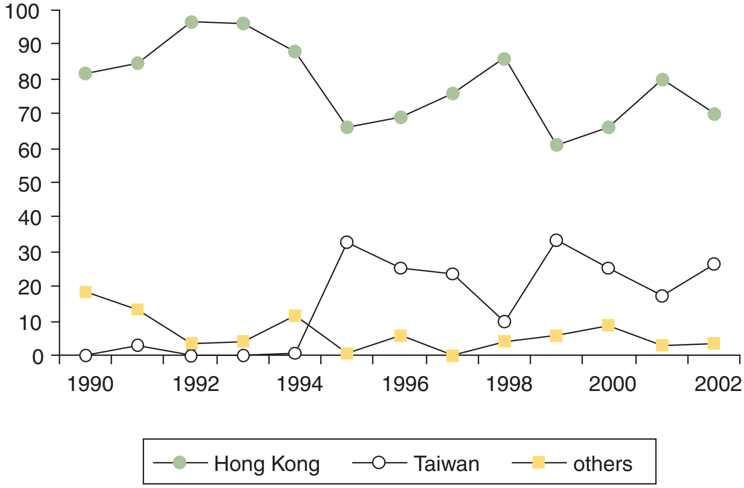

Figure 5. Annual exports of spiny lobster, Sabah, Malaysia (% annual).

- Gear — only gathering by hand/diving and pot fishing is allowed.
- Fishing grounds — all reef areas gazetted as sanctuaries or MMA (marine managed areas) are no-take zones.
- Minimum carapace length of *P. ornatus, P. versicolor* and *P. longipes* for export.
- All berried individuals must be released immediately upon capture.
- Annual export quota of 70 MT to be continued. Export season is to be restricted between the months of May to November only.

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Current Status and Exploitation of Wild Spiny Lobsters in Vietnamese Waters

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Introduction

SEVEN species of spiny lobsters are found in the Vietnamese East Sea: *Panulirus ornatus, P. homarus, P. longipes, P. stimpsoni, P. versicolor, P. penicillatus* and *P. polyphagus*. Four species — *P. ornatus, P. homarus, P. longipes* and *P. stimpsoni* — support a significant commercial fishery. These lobsters are distributed mainly in the central seawaters stretching from Deo Ngang mountain pass at the latitude of 18°N (Quang Binh province) to the spur of Ky Van mountain at latitude of 10°30′N (Vung Tau province). It means that spiny lobsters with high economic value are present in the seawaters of 14 central provinces. This distribution has provided a potential resource of lobsters in these seawaters, but the way lobsters have been exploited has varied because of the different physical geography and the sea-edge topography of each province.

Before 1975 and the reunification of Vietnam there appears to have been very little commercial exploitation of spiny lobsters. From 1975 to 1980, spiny lobsters were exploited by diving, using hooks or pitchforks as the major way of catching the lobsters. The annual catch was some tens of hundreds of tonnes per year for the domestic market. Since 1980, lobster fishing gear has improved rapidly to meet the export demand for lobsters. The old style fishing methods were replaced by trawled three- or two-layered nets, and better fishing boats enabled lobsters to be fished from further offshore, leading to catch yields increasing to 500–700 tons per year. This decade was the most prosperous period for exploiting spiny lobsters in the central waters. The size of caught *P. ornatus* reached 5–10 kg/individual, *P. homarus* was 3–5 kg/ind. and *P. longipes* and *P. stimpsoni* were 1–2 kg/ind. respectively.

During the 1990s, the size of the wild lobsters being caught continued to decrease, with more and more of the catch being of a size smaller than that demanded by the export trade. This led to the fishermen along the central coastal zone holding the undersize lobsters in simple net cages to fattened them up to a bigger and more valuable size. As these practices were found to be very profitable, more and more effort went towards catching juvenile lobsters for aquaculture ongrowing. By 2004, the number of net cages culturing lobsters has increased to about 33,000 and the cultured lobster yield is over 2000 tonnes per year. This development has not only created a new type of employment for the local villages, but it has led to more jobs and positively improved the socio-economic conditions of the coastal communities.

Spiny lobster distribution

Due to distributive features of the line-edge and topography compositions of the sea-bottom, the Vietnamese continental reefs consists of many underwater and surfacewater islands, rock and coral reefs, which provide suitable habitats for spiny lobsters during the mature period of their life cycle. The general distribution of seven spiny lobster species was studied by Cuc (1985). Based on further investigations and taking into account the databases of the sea-topography conformations and the sea-bottom sediment from Hieu (1994), the lobster fishing grounds from Cuc (1986), and the quantitative analysis of sea salt-temperature standards from Lanh (1995), the lobster fishery can be divided into three different zones with the distributive ecological characteristics as following (Fig. 1):

Zone 1: From the Gulf of Tonkin to An Luong edge (belonging to Quang Ngai Province). This is the largest zone, with the sea-bottom topography sloping gently and undivided. There are approximate 50,000 ha of reefs and rocks as well as fishing grounds in this zone. The variance of ocean salt-temperature at depth of 10 m has shown that temperatures of about 23.5–27.0°C occur in summer, and 18.0–21.5°C in winter; salinity is about 29.5–31.0% and 33.9–34.0%, respectively. *P.stimpsoni*, the only temperate species in Vietnam, is the main species found in this zone and makes up about 85% of the lobsters. Other species present, but making up only 15% of the lobster population, are *P. homarus, P. longipe*s, and *P. ornatus*.

Zone 2: From An Luong edge to Sung Trau edge (belonging to Ninh Thuan Province). This zone comprises the smallest continental reefs and the most complicated sea-bottom topography compared with the other zones. It has about 30,000 ha of reefs and rocks for fishing grounds. The salt-temperature features show a tropical region with summer temperature and salinity of 26.5–28.0°C and 33.0–34.4%, respectively and 23.5–25.2°C and 33.0–34.5% in winter. The dominant lobster species include *P. homarus, P. longipes, P. penicillatus* and *P. versicolor. P. ornatus* and *P. stimpsoni* occur at only low percentages.

Zone 3: From Sung Trau edge to spur of Ky Van mountain (belonging to Vung Tau province). It is divided into two sub-zones, one consisting of the deep waters close onshore and the other around the offshore islands. The total reefs and rocks are nearly 70,000 ha for fishing grounds. It is a completely tropical zone, with temperatures of 26.5–29.0°C and salinity of 33.0–34.0% in summer; 25.5–27.0°C and 33.0–34.0% in winter. *P. ornatus* is the dominant species, comprising about 80% of all lobsters. Other species include *P. polyphagus, P. homarus* and *P. longipes* at low percentages.

Distribution of puerulus/pre-juvenile

Detailed studies on the distribution of spiny lobster puerulus/pre-juveniles in Vietnam have not been done. However, the periodic investigations of the ocean currents of central Vietnam waters and their seasonality show that the surface current of north-east winds in winter and the inertia current of the density field in summer directly influence the wave-wind regimen and the sea current. Due to both of the currents, puerulus/pre-juveniles appear to drift into pen-bays along the central seawaters during the period from September to April.

The occurrence of peurulus/pre-juveniles is totally dependent on the suitability of the ecological conditions of the coastal bays, lagoons, and gulfs. Suitable areas are those with weak winds and waves, abundant natural food and water depths of 5–7 m. However, the distributive depth of pueruli is about 0.5–1.5 m and they prefer a sandy-mud bottom with a sediment composition mostly of fine particles and

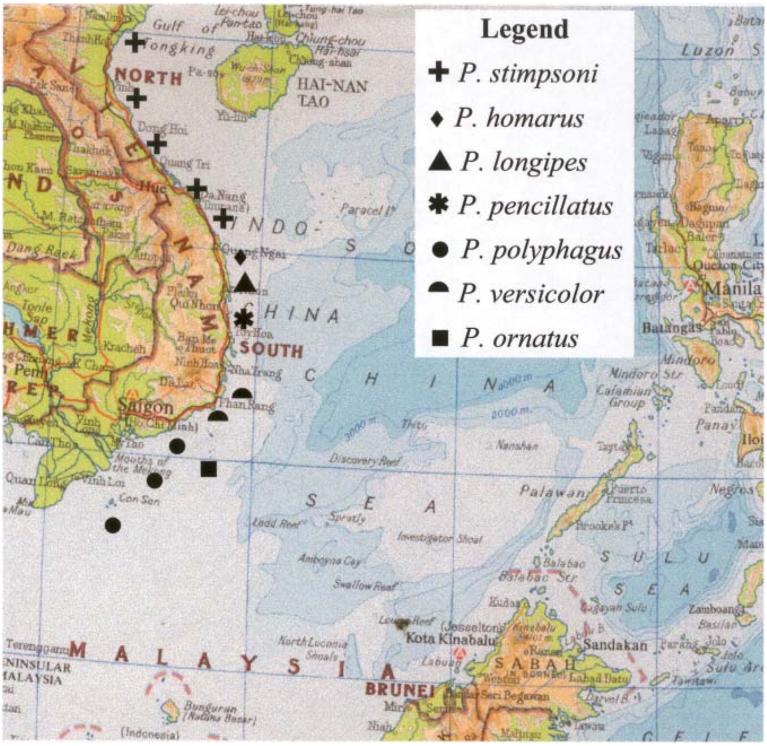

Figure 1. South China Sea map and Vietnam's location showing distribution of seven spiny lobster species.

a high concentration of organic matter. These conditions appear to be the natural nursing ground for juvenile lobsters and the locations that are actively fished to collect pre-juveniles.

The distribution of puerulus/pre-juveniles and juveniles at the bays, gulfs and lagoons has a distinct seasonal nature. The surveys have shown that puerulus/pre-juveniles of *P. homarus* appear first and typically around September. *P. ornatus*, the most dominant species, appear in very large numbers from the end of October to mid-March of the following year. Other species, but in comparatively low numbers, are found throughout the puerulus season with *P. versicolor, P. stimpsoni* and *P. longipes* occurring in descending order of number. Of five of the seven lobster species that are found in Vietnamese waters only pueruli have been recorded. The abundance and the occurrence of each puerulus/pre-juveniles in bays, gulfs or lagoons are different in quantities, time and space every year.

Exploiting lobster puerulus/pre-juveniles

The exploitation season of lobster puerulus/pre-juveniles is from January to March. Lobster seafarming has developed rapidly since 1996 and over this time the methods of catching puerulus/pre-juvenile have also changed considerably. There are now three ways of catching the puerulus/pre-juveniles in fishing communities. The preferred method of capture depends on the geographical conditions where collection occurs. At the mouth of gulfs, lagoons or bays where the sea is rather rough and water depth is about 10–15 m, the main exploitation method is to use a drawing seine net to catch pre-juveniles as they swim onshore with the incoming current. In the lagoons or bays, where the sea is rather calm and the water depth is about 1–2 m, the pre-juveniles are looking for a suitable settlement habitat. This is exploited by the fishermen, who use traps to mimic suitable settlement habitat. The traps are usually made of old nets that are rolled into a bun, or dead coral branches or domes that are drilled to provide a hole for the pre-juvenile to settle in. These traps are hung at various depths in the lagoon or bay. Traps are also made using wooden stakes of 3–4 m length, which are driven firmly into the bottom. Small holes are drilled into the wooden stakes to provide places for the lobsters to settle. A third method of collection is to snorkel dive to catch the pre-juveniles. The diving method is used for catching the pre-juveniles in shallow reefs (0.5–3 m) close to the seashore. It is estimated that about 2 million pueruli and pre-juvenile lobsters were caught in this way last season, with these then being distributed to the lobster farms along the coast of the central provinces.

Catching by net

The fishing gear is seine net with 5 mm mesh size (2a = 5 mm). The size of the seine nets depends on exploitation scale of the fishermen, but typically the net length varies from 100 m to 150 m, with a 4–6 m height. Netting operation is conducted during night-time with a 1000–2000 W fluorescent light placed at the entrance of the seine net. The net is released at around 8:00 pm and after 4–5 hours (around 12:00–1:00 am), it is hauled into the boat and the pueruli are gathered. The net is then released again and collected around 4:00 am for the second harvesting. Netting operation terminates at around 5:00 am of the next day.

The size of the collected pueruli are very similar. They are about 7–8 mm in total length, are transparent and weigh about 0.25-0.35 g. The surveyed data on catching by seine net at some of the bays and gulfs during three years in Phu Yen province showed that pre-juvenile numbers have increased and *P. ornatus* is the dominant species of puerulus/pre-juveniles of *P. ornatus* caught (Table 1).

Catching by trap

Traps are often made of nets of about 60 cm in length and about 40 cm in diameter. Where drilled coral is used for the trap, the size of the coral pieces used varies according to what coral is locally available. Most of the coral pieces are coral blocks of 2–5 kg in weight. The surface holes are drilled at 10–15 cm intervals and are 2–2.5 cm in diameter. Wooden traps are drilled to make holes in the same way as those of the coral ones. In November every year, the time

Table 1. Total number of puerulus/pre-juveniles by caught seine net at Xuan Dai bay, Xuan Hai and Hoa An gulfs of Phu Yen province during 2000–2002.

Species	Number of lobster puerulus (animals) caught			Percentages (%)
	Year 2000	Year 2001	Year 2002	
P. ornatus	25,827	60,224	126,764	99.0
P. homarus	1070	472	561	1.0

when lobster pre-juveniles are expected to be found, traps are set into water at a depth of about 4–5 m. After 3–5 days of being placed, every morning fishermen collect the lobster pre-juveniles by shaking the traps so that the lobster fall into a ring-net. Alternatively, in shallow water, the pre-juveniles can be manually picked from the drilled holes. The size of the collected pre-juveniles vary from 7.5–10 mm in carapace length and 0.3–1 g in body weight. During the peak collection period of January–February, as many as 50–200 individuals might be taken by one fisherman.

Catching by diving

Diving to catch the pre-juvenile is the most traditional method of collecting lobster pre-juvenile by fishermen in central coastal Vietnam. This method results in larger juveniles being caught, from 12–15 mm carapace length and 7–9 g body weight, and these have the best survival during culture. However, the maximum catch is only 100–150 pre-juveniles for a boat with five divers for 10 days of operation during the main fishing season.

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Session II
LOBSTER AQUACULTURE IN THE PHILIPPINES AND VIETNAM

Le Anh Tuan

Staked lobster cages at Xuan Tu village, Khanh Hoa, Vietnam.

Sustainable Farming of Spiny Lobster in Western Mindanao, Philippines

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There are biological and technological criteria often cited as prerequisites for any potential species for culture. This study tabulates some measured criteria for some candidate species (*Trachinotus blochii, Rachycentron canadium, Latis calcarifer*, *Lutjanus argentimaculatus, Carranx sp*, etc) for culture in southern Mindanao against the performance of spiny lobster, *Panulirus sp*. in western Mindanao, Philippines. The tabulation will be presented during the proper workshop. However, my highlights will focus on the performance of spiny lobster in Zamboanga del Sur, where the most commonly caught spiny lobsters in the area are the *Panulirus ornatus, P. versicolor* and *P. longipes* complex. In Zamboanga Peninsula, an annual production of 90 metric tonnes of spiny lobsters can still be sustained.

A high demand for spiny lobsters has created a lucrative market, but harvesting it from the wild without understanding the biology and its habitat has depleted the lobster population in most areas of western Mindanao. In 1984 the bulk of about 241 MT landed lobsters (DA-IX Municipal Production Report 1985) were coming from Basilan and in the east and west coast of Zamboanga City (Pers. comm. 2004). At the present time, in all provinces in western Mindanao lobster farming has declined, particularly in the province of Basilan. This is due to non-selective hunting (even egg-bearing lobsters were caught and fattened; eventually they died and were sold very cheaply). There were, however, some initiatives undertaken in Zamboanga del Sur that were triggered by a surprising observation that resulted in some enthusiasm to revive the present fattening production system into a sustainable culture of spiny lobster.

Culture practices

The usual stocking density in floating cages (Fig. 1) was only eight juveniles/m^3. Sometimes it varied depending on the supply of young juveniles which peaked from October to March in western Mindanao, but in southern Mindanao it starts to peak from March to August (Menez 2004). The preferred initial weight for stocking was 100–300 g, and it took 6–15 months of feeding to reach the optimum size of 800g–1.3kg. Fishery by-catch were commonly used to feed the lobster. Stocking at this size can reach up to 90% survival, even after up to 18 months of culture. Stocking of smaller size between 30–80 g results in less than 50% survival. However, the limiting factor here was not the size of the lobster at stocking, nor the availability of foods, but because the artificial shelters had been designed for the bigger lobster. It was also observed that although spiny lobsters are nocturnal they could easily adapt to confinement, and feeding during daytime was not a problem. Trash fish cost only US$0.13–0.22 per kilo, but to date the retail price of live tiger lobster (*Panulirus ornatus*) delivered to the local broker in Zamboanga City is US$21–31/kg; hence a wet FCR of more than 10 can still be profitable. However, farmgate price can be as low as US$15.00 for live ornate lobster and even less than US$12.00 for some species such as *P. versicolor*. Some local buyers will reduce the price

J. Arcenal

Figure 1. Lobsters in floating cage at partial harvest after eight months of culture (initial body weight at stocking = 150 g, stocking density = 8/m^3).

further for cultured lobster. They justify the lower price because, according to them, the taste and color of the cultured lobster is inferior to the wild lobster. Hence, the development of feeds for cultured spiny lobster has to take into account not only the growth rate achieved by the lobsters but also the taste and color of the harvested product in comparison to that of the wild stock.

Key to sustaining lobster culture: No MPA, No Lobster Policy

The life cycle of the spiny lobster is very complicated: the eggs hatch as tiny spider-like transparent larvae or phyllosoma which then undergo 11 distinct morphological stages and up to 17 moults over 12 to 18 months, or 24 months before the larval stage is completed and the lobster is ready to settle (Lipcius and Cobb 1994). Because of the protracted larval development, no commercial hatchery has successfully supplied post phyllosoma for aquaculture ongrowing. The attempted larval rearing of the ornate lobster at the marine laboratory in the nearby province of Zamboanga del Sur was not feasible due to a very low survival expected (almost zero).

Hence, lobster sanctuaries within the designated Marine Protected Areas (MPA) were conceptualised and established. Nature tithing was then formulated in order to return 10% of the farmed grown matured lobsters (>1.5 kg) back to the designated lobster sanctuary. It is hoped that this practice would assist stock replenishment, and, in concert with sound conservation measures, would ensure a sustainable wild population. But there are some precautionary measures that must be observed. Cultured lobsters, when released to their natural home, are susceptible to predation because they seemed to have a 'culture shock' and forgot for some days that they are supposed to be a nocturnal species. It is also more effective if the lobster sanctuary is chosen because of its similarity to the natural habitat of the lobsters and not because of a site's accessibility for the fishers. This is because spiny lobsters seem to be like a homing pigeon. New studies (Lohmann, K.J., et al. 1995; Boles, L.C. and Lohmann K.J. 2003) have showed that lobsters have a well-developed GPS (geographical positioning system) faculty that enables them to figure out their geographic location. The triggering phenomena in Zamboanga del Sur (September 2000) was when the berried spiny lobsters were purposely stocked in the floating cages to hatch them in captivity and let them grow under the mercy of the current. Surprisingly, after a couple of months, some newly settled pueruli were noted in the artificial shelters but they disappeared after a few days. However, after some months young 'returnees' were seen in the lobster cage again and also in the adjacent bamboo cage which was being used for siganid culture. Although the recovery here was very insignificant, it was enough to convince the fishers that there is a need to establish a lobster sanctuary within the marine protected areas if they wanted to culture the lobster in a sustainable way. It is just like saying that to grow lobster they have to be let go and even if their growing is at some distance away their eventual return means that they are meant to be sustained.

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Present Status of Lobster Cage Culture in Vietnam

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Introduction

In 1992, marine cage culture was developed in the form of lobster culture in Khanh Hoa province based on the study conducted by Ho Thu Cuc (UoF) in collaboration with Khanh Hoa Department of Fisheries. By 2003 there were more than 35,000 lobster cages in the whole country (Phuoc, N.H, Bao, T.N.N, Lien N.T., Phu, L.B, Hoa, N.T., Lam, N.V, Lam, P.V. 2004, Pers. comm.). The main culture areas are Khanh Hoa, Phu Yen and Ninh Thuan provinces (Fig. 1).

The main species cultured is the ornate lobster *Panulirus ornatus*, with only small numbers of *P. hormarus, P. timpsoni*, and *P. longipes* also cultured (Tuan et al. 2000). Lobster cage culture has great potential to develop in Vietnam. There is a 3200 km–long coastline, an exclusive economic zone (EEZ) of one million square km, more than 4000 islands, and many lagoons and bays that are suitable for cage culture (MOFI 1994).

Issues

Seed

Lobsters are distributed mainly in the Central Sea from Quang Binh province to Binh Thuan province. Among nine identified species in the region, three species have rapid growth, large size, bright colour, and high export-value. These are *Panulirus ornatus, P. hormarus,* and *P. stimpsoni. P. longipes* is also cultured, but in small quantities. In general, each species has its own distribution area. For example *P. ornatus* is found mainly in Ninh Thuan Sea and *P. stimpsoni* in Quang Binh-Quang Tri Sea (Thuy 1996; Thuy 1998).

There have been some studies on seed production of lobster (*P. ornatus, P. homarus*) in the Research Institute for Aquaculture No. III (RIA III) in Nha Trang, but the results have not been recorded. At the present time, lobster seed is sourced from the wild. Lobster seed was transported mainly from northern central provinces such as Hue, Da Nang, Quang Nam, Quang Ngai and Binh Dinh to meet the demand in southern central provinces, including Phu Yen, Khanh Hoa and Ninh Thuan. However, farmers prefer to stock local seed because of the seed quality. The demand for the lobster seed has increased markedly. It is estimated that demand has increased from less than 500,000 animals in 1999 to approximately 3,500,000 animals in 2003 for the whole region (Tuan, in press).

Figure 1. Major lobster culture areas in Vietnam.

Knowledge of the fishery is still inadequate to be able to determine the maximum sustainable yield, and this information is unlikely to be available in time to be useful for management purposes. However, price gives a reasonable indication of the relationship between supply and demand, and this has increased significantly in recent years for all sizes of lobsters, suggesting a shortage of supply and the possibility of over-exploitation (Fig. 2).

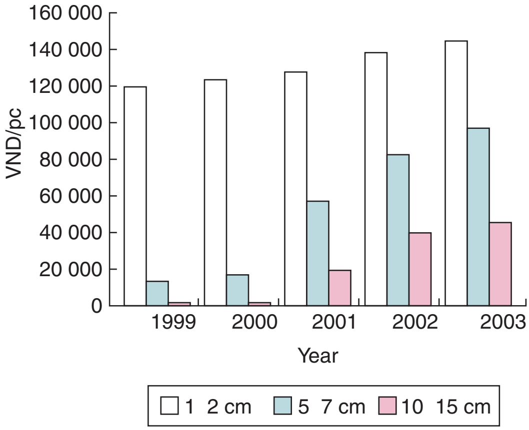

Figure 2. Price trends for lobster seed in Khanh Hoa Province, Vietnam (1 US$ = ca. VND 15,700).

Cage

Cages are designed in various ways depending on the characteristics of the culture areas and the farmers' financial conditions (Table 1).

Floating cage: The bag of the floating cage is normally supported by a frame with buoys. Lobster cages in the Nha Trang bay (Khanh Hoa) belong to this type of cage. Cages in this category are commonly located in waters with a depth of 10–20 m, for example in the Nha Trang bay (Fig. 3).

Wooden fixed cage: The framework is made of salt-resistant wood. Wooden stakes of 10–15 cm diameter and 4–5 m length are embedded every 2 meters so as to create a rectangular or square shape. The bottom area of a farm is normally 20–40 square meters, but may be as much as 200–400 square meters. The cage size also varies. Each cage normally has a cover. The cage may be on, or off, the bottom. A fixed off-bottom cage is typically about 0.5 m above the sea bed. A fixed on-bottom cage is lined with a layer of sand. This kind of cage is suitable for sheltered bays and behind islands where there is shelter from big waves and typhoons. They are common in the Van Phong bay, Khanh Hoa Province (Fig. 4).

Table 1. Summary of commonly used cages for spiny rock lobster in Vietnam.

Cage				
Type	Shape and size	Frame	Bag	Culture Area
Floating	Bottom: rectangular; Various size: 3 × 2 × 2, 3 × 3 × 2, 4 × 4 × (1.5–4), 3.5 × 3.5 × (1.5–4), 3 × 4 × (1.5–4) m, etc.	Salt-resistant wood, vertical wood: ϕ = 15–20 cm; horizontal: ϕ = 12–15 cm and buoys	outer net: 2a = 10–15 mm; inner: 2a = 2–4 mm	Sites with depth of 10–20 in bays (Khanh Hoa)
Fixed	Bottom: rectangular, square Various size: 2 × 2 × (1.5–4), 3 × 3 × (1.5–4), 3 × 4 × h[A]; 4 × 4 × h[A] m, etc.	Salt-resistant wood, vertical wood: ϕ = 15–20 cm; horizontal: ϕ =7–10 cm	outer net: 2a = 20–50mm; inner: 2a = 2–4 mm	Shallow sites in bays (Phu Yen, Khanh Hoa)
Submerged	Bottom: rectangular, square; Various size: 0.7 × 0.8 × 1.2[B], 1 × 1 × (0.8–1.2)[B]b, 1.5 × 1.5 × 1.2, 2 × 2 × (1.2–1.5), 3 × 3 × 1.5, m etc.	Iron, ϕ = 18–20 mm; plastic feeding pipe, ϕ = 10–12 cm	outer net: 2a = 30–35 mm; inner: 2a = 2–4 mm	Shallow sites in bays (Phu Yen, Khanh Hoa, and Ninh Thuan)

[A]The height of cage, depending on site, normally equivalent to the height of the highest tide.
[B]Nursery cages.
Sources: Tuan et al. 2000; FEC-Ninh Thuan 2000; Lieu, P.T.T 2003.

Submerged cage: The framework is made of iron with a diameter of 15–16 mm. The bottom shape is rectangular or square with an area normally between 1 and 16 square meters. The height is 1.0–1.5 m. The cage has a cover and a feeding pipe. This kind of cage is common for nursing lobster seed in Nha Phu lagoon, and for grow-out farming in the Cam Ranh bay in Khanh Hoa, and in Ninh Thuan, Phu Yen provinces (Fig. 5).

Le Anh Tuan

Figure 3. Floating cages.

Le Anh Tuan

Figure 4. Wooden fixed cages.

Materials for making cages such as wood, iron, net, etc. are available in Vietnam. The marine cages are often of small size suitable for family-scale operation. That is why the number of cages has increased significantly in recent years. While individual developments may have no significant impact on the environment or society, a large number of developments, however small, may have significant impact on the wider social and economic environment, and on each other.

Le Anh Tuan

Figure 5. Submerged cages.

Feed

Lobsters are fed exclusively with fresh whole or chopped fish and shellfish. The most commonly used species/groups for feeding lobster are Lizardfish (*Saurida spp*); red big-eye (*Priacanthus spp*); Pony fish (*Leiognathus spp*); pomfret; snails, oyster and cockles; small swimming crab, other crabs and shrimps. Finfish comprise about 70% of the diet, with 30% shellfish. The preferred fish (comprising 38% of fishes in diet) was lizardfish.

Farmers showed active selection of the preferred fish species, using a consistently higher proportion than present in typical trash fish landings (Fig. 6), and using a higher proportion of lizardfish in particular, despite a significantly higher price (average VND 5000/kg) associated with this species. The food

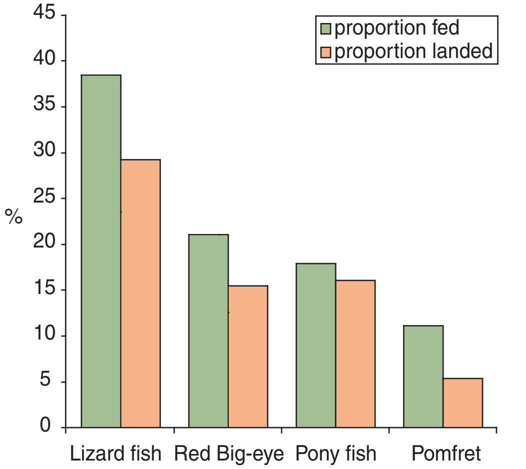

Figure 6. Preferential selection of trash fish species by lobster farmers.

conversion ratio for lobster using this diet is high at around 17–30 (fresh weight basis).

Small-size lobsters are fed 3–4 times per day, with a greater proportion fed in the evening. Trash fish is chopped into small pieces, and mollusc shells were excluded. Large-size lobsters (>400g/pc) are fed 1–2 times per day. For this size of lobster, there is no need to chop trash fish nor to exclude mollusc shells. The feeding intensity of lobster increase strongly just before moulting. In the last few months of a culture cycle, the amount of shellfish (molluscs, crustacean) fed to the lobsters is generally increased and the amount of trash fish is decreased. Feeding trash fish typically results in poor FCRs and has resulted in water quality problems; for example, the total nitrogen content in the sea water exceeded the standard level for aquaculture of 0.4 mg/L in some sites in Xuan Tu, Khanh Hoa (Tuan, in press).

Disease

In the past, lobster diseases rarely occurred. Recently, however, stocking lower quality seed (i.e. seed at puerulus stage, seed transported long distances from the culture area, seed caught using harmful fishing methods such as high-pressure lights, etc) and culturing in poor quality water (due to a rapid increase in the number of cages) have resulted in some diseases in cultured lobsters in some areas (Table 2).

Some preliminary studies (FEC-Ninh Thuan 2000) showed that the main pathogens occurring in infected lobsters were two bacteria, *Aeremonas hydrophyla* and *Proteus rettgeri,* two fungi, *Fusarium solari and Lagenidium sp* and parasites *Baranus spp*, *Zootharíniu* and *Vortiella*.

Economics

The estimated total annual production of farmed spiny rock lobster is currently about 1500 metric tonnes a year with a farmgate value of US$ 40 m (VND 420,000 per kg (ca US$ 26.75/kg)). The average profit margin is 50%. Therefore, lobster cage culture is a profitable industry and involves more than 4000 farmers/households and creates many employment opportunities for local village people. However, the stability of the market is one of the major concerns of the farmers.

Further research needs

Studies should focus on determining the maximum sustainable yield of lobster culture and address those issues that will provide some advice on immediate practices that could be instituted to better manage sustainable lobster culture. Lobster propagation should be studied intensely as a long-term goal for industry sustainability. More attention should be paid to nutritional requirements and improved feeds for nursing and growing-out lobster. Additionally, optimum feeding regimes should be studied not only in laboratories but also on farms. Disease protection measures should be prioritised at this time at both farm and water body levels. The quality of lobster seed, as well as feeding techniques, should be assessed with respect to the health and vitality of the seed. Cage designs should be studied to make comparative assessments and recommendations for improved lobster husbandry. Cage density allocation for one water body should be developed based on studies of carrying capacity. Market structure, market stability and its potential expansion should be studied.

Table 2. Some common diseases in cultured lobster in Vietnam.

Year	Disease	Signs	Protection and Treatment	Damage
1998	Black gill	Dark gill	Remove cages Formalin 100 ppm/3–5 m	Mortality 1–2%
1999	Black gill	Shell necrosis Shell eroded, flesh ulcerated	Formalin 100 ppm/3–5 m	Mortality 1–2%
2000	Black gill Shell necrosis	Shell necrosis Shell eroded, flesh ulcerated	Formalin 100 ppm/3–5 m	Mortality 2–3%
2001	Black gill Shell necrosis Red body	Shell eroded, flesh ulcerated Red body	Formalin 100 ppm/3–5 m	Mortality 2–3%
2002	Black gill Shell necrosis Red body	Shell eroded, flesh ulcerated Red body	Formalin 100 ppm/3–5 m	Mortality 2–3%

Sources: Lieu, P.T.T, 2003.

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Session III
LOBSTER ECOLOGY AND TRANSPORT

Kevin Williams

Recently settled juvenile ornate lobster, *Panulirus ornatus*.

Ecology and Stock Assessment of the Ornate Rock Lobster *Panulirus ornatus* Population in Torres Strait, Australia.

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Introduction

THE emergence of cage culture of the ornate rock lobster *Panulirus ornatus* (Fabricius 1798) in Vietnam has resulted in the establishment of a thriving industry worth US$75m in 2001–02. The industry relies on settling lobsters that are harvested from the wild and on-grown in floating sea cages and practically replaces the previous wild fishery for adults. Whilst cage culture continues to flourish in Vietnam, the long-term sustainability of this practice has been questioned, particularly the impacts on the local wild population.

In Australia, the ornate rock lobster supports a small but locally important commercial wild-caught fishery in Torres Strait. The fishery, worth ~$A8 million annually, is shared by Australia and Papua New Guinea and is the major source of income for Torres Strait traditional inhabitants. For these reasons the Torres Strait lobster population has been the focus of biological and fishery research carried out by CSIRO Marine Research and PNG Fisheries during the past two decades. More recently, with impetus from the success of cage culture in Vietnam, there has been interest from industry and management to grow-out juvenile lobsters in cages in Australian waters.

This paper presents a review of the results of ecological and stock assessment research on *P. ornatus* in Torres Strait. This review will hopefully provide some relevant information to address the likely sustainability of the current cage culture practices in Vietnam and possible methods to monitor the current and future status of the local lobster population.

Torres Strait Lobster Fishery

The Torres Strait lobster fishery extends from the north-east tip of Australia to south-west Papua New Guinea (Fig. 1) and is managed by the two countries in accordance with the Torres Strait treaty signed in 1985. The commercial fishery in Torres Strait began in the late 1960s, after a processing factory was established on Thursday Island. Torres Strait Islanders fish largely from their island communities, while a small fleet of Thursday Island-based freezer boats travel to the main fishing grounds on neap tides. Ornate rock lobsters from the same stock are also fished along the north-east Queensland coast (Fig. 1).

As ornate rock lobsters in Torres Strait waters do not enter baited traps, they are taken by divers with spears or are caught alive with hand-held scoop nets. Divers generally work in pairs from small dinghies and either free-dive or use a 'hookah' that supplies compressed air from the surface. Free-divers work in waters to about 5 m deep, while hookah divers work in waters to around 25 m. This species was also taken by trawling prior to 1984 when a ban was placed on this practice to conserve emigrations of breeding lobsters.

The Australian Torres Strait lobster fishery is managed by the Australian Fisheries Management Authority (AFMA) under the Protected Zone Joint Authority (PZJA). The fishery is managed to protect the livelihood of traditional inhabitants. There are about 350 islander vessels and 20 non-islander freezer vessels operating in the fishery. The non-islander sector is capped and no new licences will be issued. New management was implemented in 2002 in response to concerns that the fishery was unsustainable and outputs of CSIRO fishery modelling. There is a seasonal ban on all fishing during October–November and a ban on the use of 'hookah' equipment during December-January. The minimum legal size is 115 mm tail length or 90 mm carapace length. The fishery was based solely on frozen lobster tails, sold on the domestic and overseas (mainly the United States) markets, until the mid-1990s. Subsequently, the trade in live lobsters has continued to grow with established domestic and export markets for them. The conversion from frozen tail to live product was actively encouraged by management as each live animal is about 2.5 times more valuable than its frozen tail.

The annual catch of ornate rock lobster by Australian divers in Torres Strait during the past two decades ranged from 130 t to 350 t (tail weight) and averaged 205 t, whilst PNG divers averaged about 80 t (Fig. 2). Annual catches trended upwards through the 1990s, but declined dramatically during 1999 to 2001, raising concerns that the fishery was unsustainable. However, since then stock abundance has increased steadily and recent catches are around the long-term average.

Lobster Ecology

Emigration and reproduction

After two years spent on the Torres Strait fishing grounds all ornate rock lobsters emigrate to breed. Early studies by Moore and MacFarlane (1984) and Bell et al. (1987) showed that the sub-adult lobsters (2.5 years old) migrate out of the Torres Strait fishery in spring (August–September) and move as far as the eastern Gulf of Papua (Fig. 3) to mate and spawn

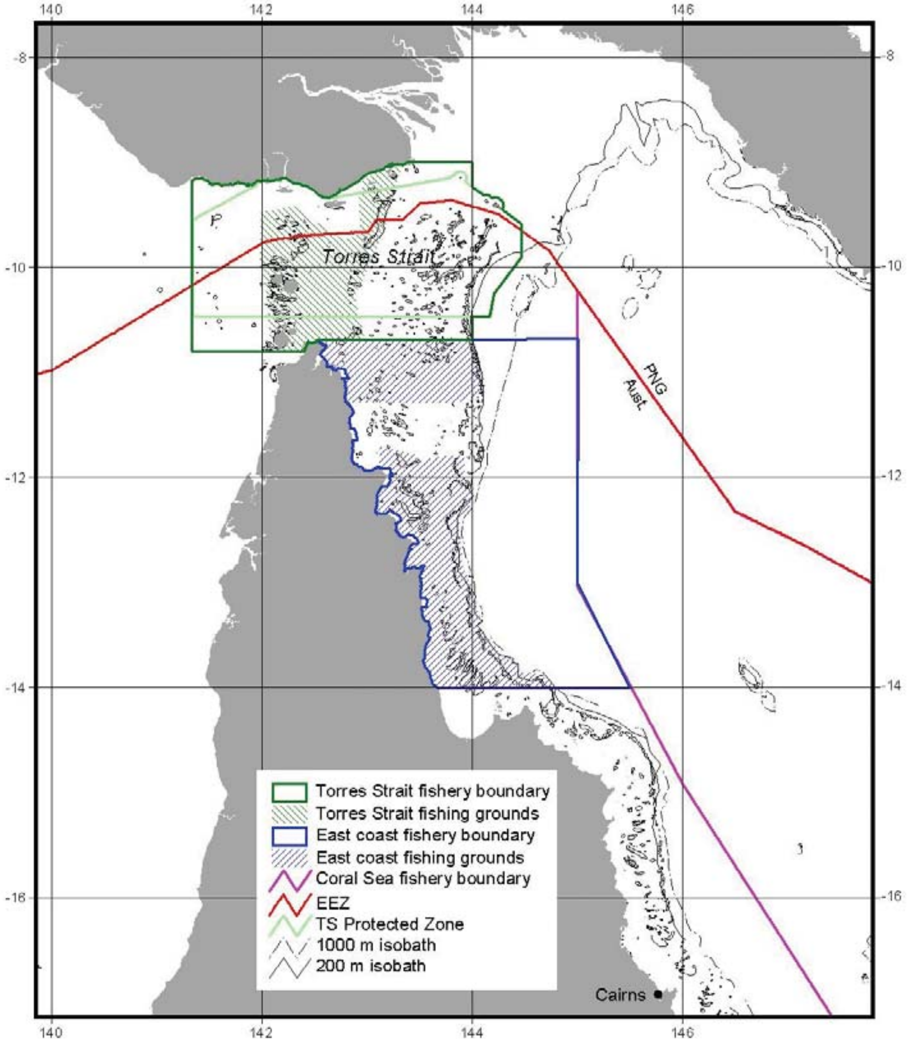

Figure 1. Map of Torres Strait and northeast Queensland, Australia showing location of the lobster fishery and boundaries of the fishery jurisdictions.

during the ensuing summer (November–February). MacFarlane and Moore (1986) documented the reproductive dynamics of *P. ornatus* at Yule Island, PNG and found no return migration after breeding. Subsequent studies at Yule Island showed that the breeding population suffered catastrophic mortality following the breeding season due to the combined stresses of migration and reproduction (Dennis et al. 1992). This information highlighted the need to conserve the breeding migrations from Torres Strait. Deep-water diving and submersible surveys have shown that breeding also occurs on the far northern Great Barrier Reef during summer (Prescott and Pitcher 1991). The source of these breeding lobsters is unknown but most likely they would have originated from the Torres Strait.

Bell et al (1987) established that the ornate rock lobster population on the Queensland coast did not participate in the extensive breeding migration across the Gulf of Papua undertaken by Torres Strait lobsters. Further, since Queensland lobsters do not embark on extensive breeding migrations, females breed in successive years. This is in contrast to populations in the eastern Gulf of Papua that suffer catastrophic mortality after breeding.

Berried female ornate rock lobsters have been found over a wide geographic extent around the northwest Coral Sea from Cairns, Queensland to Yule Island, Papua New Guinea (Fig. 4). They have been found at depths greater than 100 m on the far north Great Barrier Reef and eastern Torres Strait during deep-water breeding ground surveys, and it is likely some lobsters move to the continental shelf off the northeast Queensland coast to spawn. Apart from the Yule Island breeding population, relatively little is known of the size and extent of the remaining breeding grounds and their likely contribution to recruitment into each of the fisheries. However, recent larval advection modelling by Dr David Griffin (see details in the author's workshop paper) has shown that larval output from most known breeding populations has a high likelihood of settling back into the fishery grounds.

Larval Ecology in the northwest Coral Sea

Oceanic transport of ornate rock lobster larvae in the northwest Coral Sea is largely influenced by the influx of warm equatorial water flowing westward in the South Equatorial Current (SEC) that enters between the Solomon Islands and Vanuatu (Fig. 5). Upon reaching the Great Barrier Reef (GBR) at between 14° and 18°S the SEC bifurcates, with about equal volumes feeding south into the East Australian Current (EAC) and north along the GBR into the Gulf of Papua (Andrews and Clegg 1989). The presence of a closed gyre, called the Coral Sea Gyre (CSG), was confirmed by the trajectory of a satellite-tracked drifter deployed at 14°S, 149°N, that performed a clockwise loop of about 500 km diameter over a period of four months (Burrage 1993).

Overlaying the ocean currents are the prevailing winds that are predominantly northwest in the summer monsoon (November to March) and southeast trade

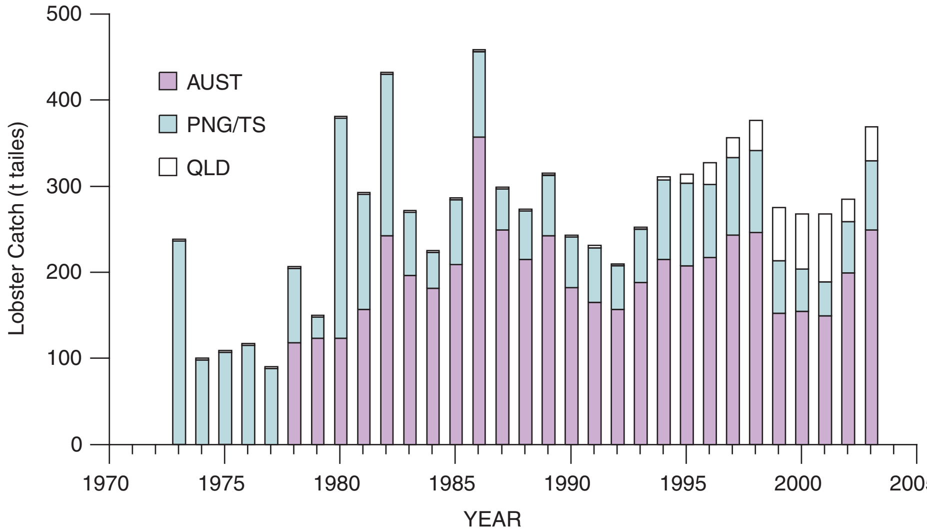

Figure 2. Annual catches of *Panulirus ornatus* landed in the Australian and PNG Torres Strait fisheries and the Queensland coast fishery during 1973–2003. Catches for 2001–2003 are approximates.

winds during the winter (April to October). With this fundamental oceanographic information in mind, CSIRO Marine Research planned and undertook a plankton survey in the northwest Coral Sea during May 1997 to document the distribution and abundance of *P. ornatus* larvae, relative to the main ocean currents (Fig. 5).

Prior to the May 1997 survey, the larval life of *Panulirus* species in eastern Australian waters had not been documented, apart from an observation of late stage phyllosomes in a warm-core eddy, pinched off from the EAC, off southeastern Australia (McWilliam and Phillips 1983). However, this occurrence was thought to represent larval attrition, rather than a regular dispersal mechanism to adult habitat.

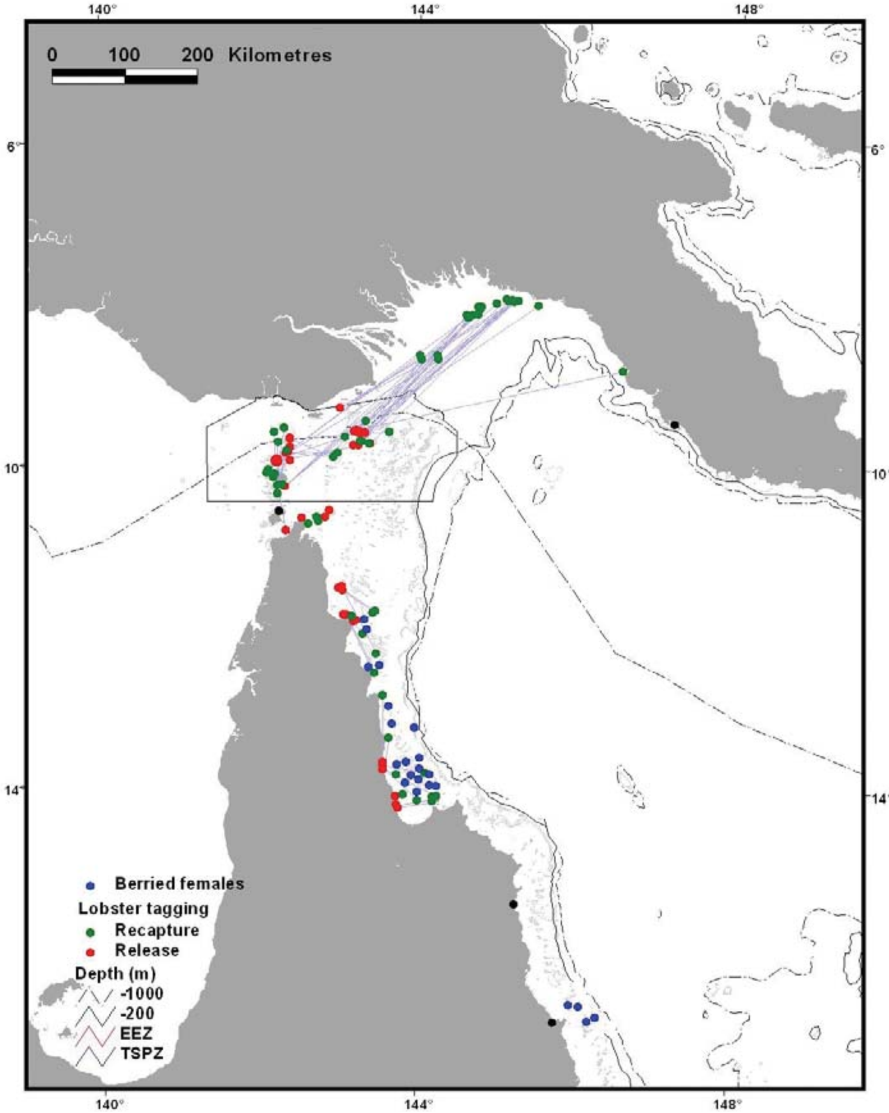

Figure 3. Map of northwest Coral Sea showing movements of ornate rock lobsters *P. ornatus* from tag-recapture studies conducted by CSIRO and PNG Fisheries during 1975–1984.

In May 1997, all stages of *P. ornatus* were generally restricted to the south and west Coral Sea (Fig. 6) and there were virtually no larvae along the southern Papua New Guinea coast. The larvae would have been between three and six months old, given that peak larval release occurs between late-November and mid-February (MacFarlane and Moore 1986). Most of the phyllosoma catch was taken well offshore, at the southern margin of the Coral Sea Gyre.

Late-stage (6–17.5 mm TL) phyllosomas comprised about 35% of the total phyllosoma catch and were most abundant 300 km off the north-east Queensland coast, and near the shelf-break between 14° and 12°S (Fig. 6a). Sub-final stage (17.5–24 mm TL) phyllosomas comprised about half of the total phyllosoma catch and were generally restricted to the off-shore locations (Fig. 5b). Final-stage (gilled) (>24 mm TL) phyllosomas comprised

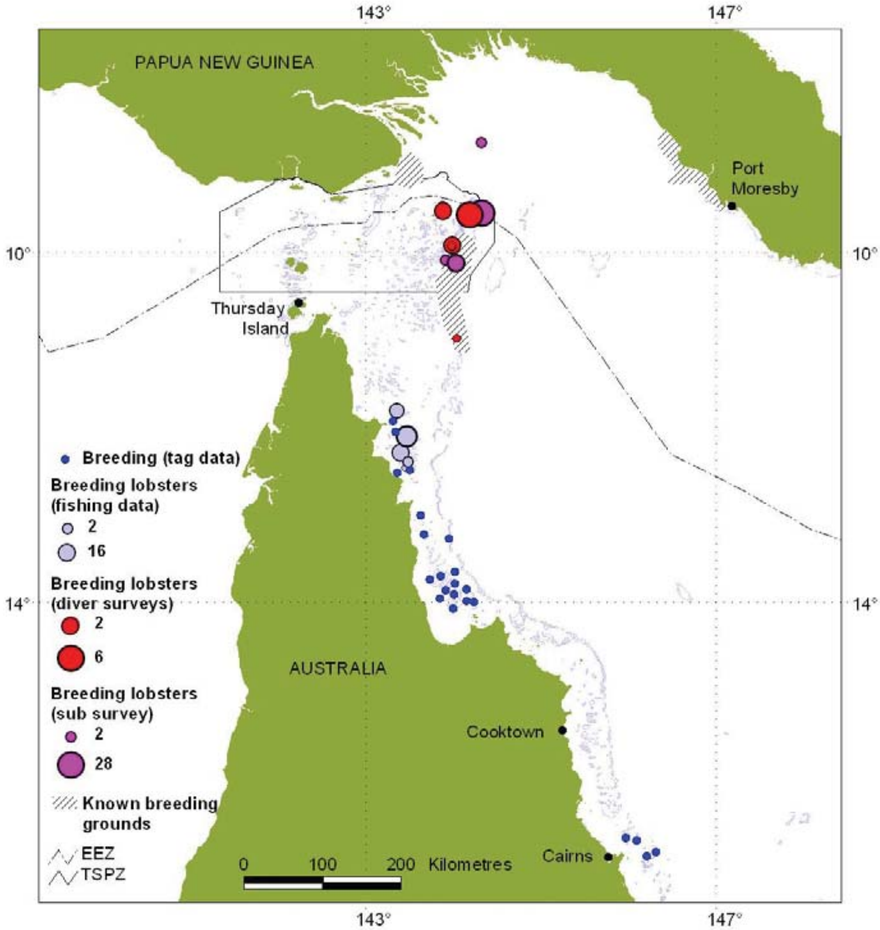

Figure 4. Map of northwest Coral Sea showing locations of breeding ornate rock lobsters *P. ornatus* from fisher observations and research surveys. Hatching shows likely extent of known breeding grounds. The areas of plotted circles are proportional to the number of breeding lobsters found in the surveys (note that the scales indicated by the numbers are not the same for the different survey methods).

about 15% of the total phyllosoma catch and were most abundant off-shore and at locations adjacent to the northern Great Barrier Reef (Fig. 5c). Pueruli comprised about 4% of the total *P. ornatus* catch and were most abundant on the Great Barrier Reef shelf-break (Fig. 5d), although surprisingly some pueruli were caught about 600 km east of the Great Barrier Reef. Most *P. ornatus* pueruli were caught at the surface (<0.5 m).

Settlement timing

Attempts by CSIRO to collect newly-settled ornate rock lobsters in Torres Strait using artificial surface collectors (for example Phillips, Lewis and Booth-type designs) have been largely unsuccessful to date. It is likely that the failure of collectors was mainly due to very low densities of recruits and the availability of suitable seabed habitats. Intensive searches of seabed transects in Torres Strait by CSIRO divers in 1992–93 showed that the density of newly-settled lobsters in their natural habitat is very low (63 ha^{-1}, Dennis et al. 1997). Further, pueruli must traverse ~100 km of shelf habitat in Torres Strait prior to settling in suitable juvenile habitat, and its likely mortality is high during this journey.

Settlement timing for *P. ornatus* was studied at Cairns, Queensland during 1981–1985 by divers sampling wharf piles. Peak settlement occurred during winter (June–August) in most years (Fig. 7).

A total of 263 newly-settled ornate rock lobsters were observed during intensive searches of seabed transects in Torres Strait by CSIRO divers during monthly sampling between August 1992 and March 1993. However, no pueruli were observed, suggesting the initial settlement habitat may be different to that of juveniles. However, monthly sampling of post-puerulus lobsters allowed settlement timing to be estimated by back-calculating growth (Fig. 8). The mean estimated date (June) coincided with the lowest water temperature for the year. Annual fishery-independent sampling of the Torres Strait lobster population by CSIRO showed that mean sizes of 1+ and 2+ year-old lobsters were consistent in different years (Fig. 9). This suggests that settlement timing is also generally consistent in different years.

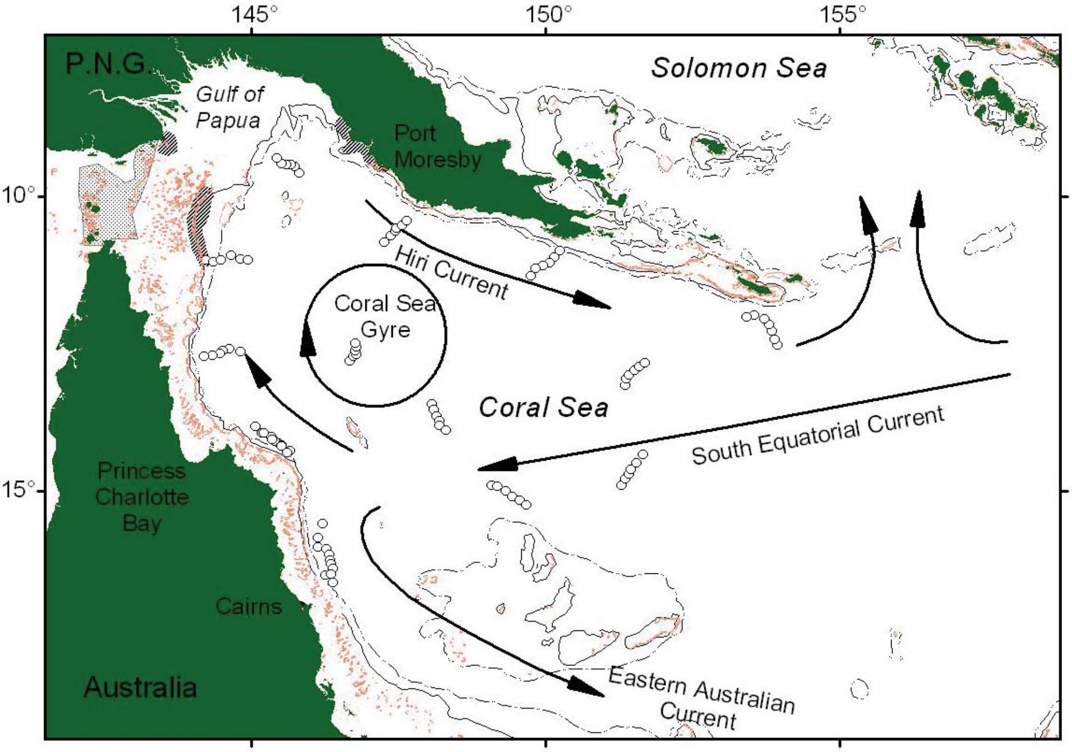

Figure 5. Map of the northwest Coral Sea showing major near-surface ocean currents, breeding grounds of *P. ornatus* (hatched line), the Torres Strait fishery (dotted area), and the 13 sampling locations surveyed during May 1997 (circles). The solid and dashed lines represent the 200-m and 1000-m isobaths, respectively. (Dennis et al., 2001)

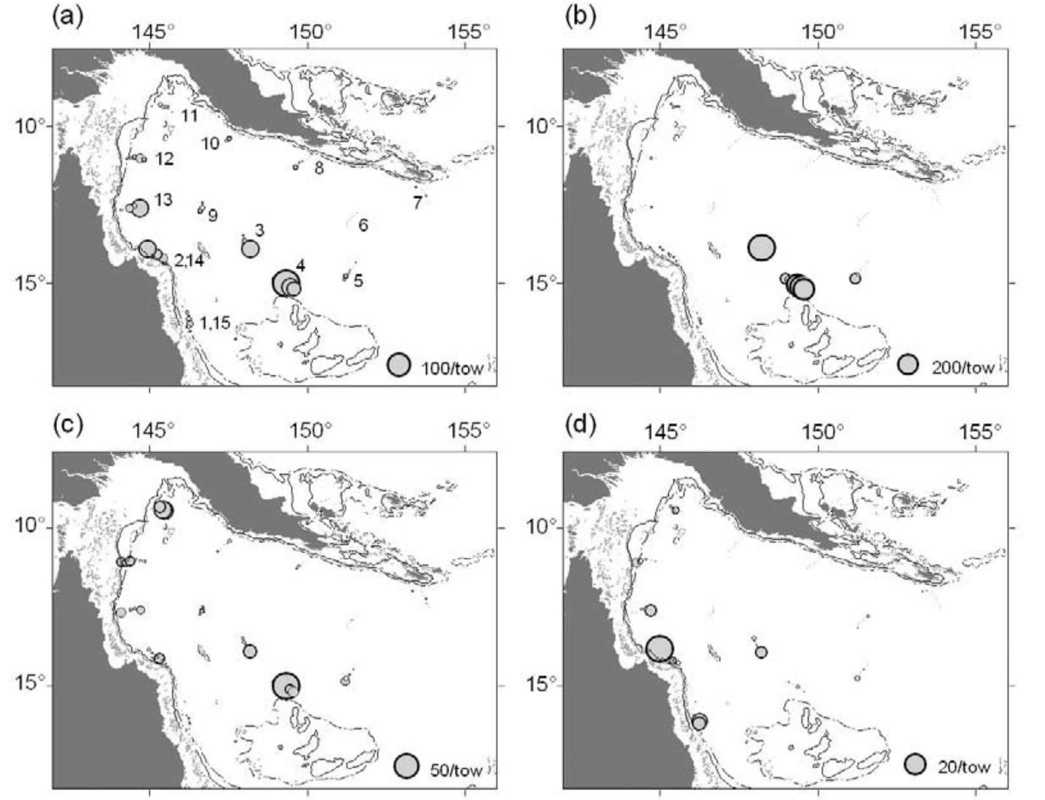

Figure 6. Geographic distribution of *P. ornatus* phyllosomas: a) late stages; b) sub-final stages; c) final (gilled) stages; and d) pueruli, caught in 150–minute plankton tows in the northwest Coral Sea during May 1997. The areas of plotted circles are proportional to numbers of larvae caught per tow (note the scales are not the same in each of the panels). (Dennis et al. 2001)

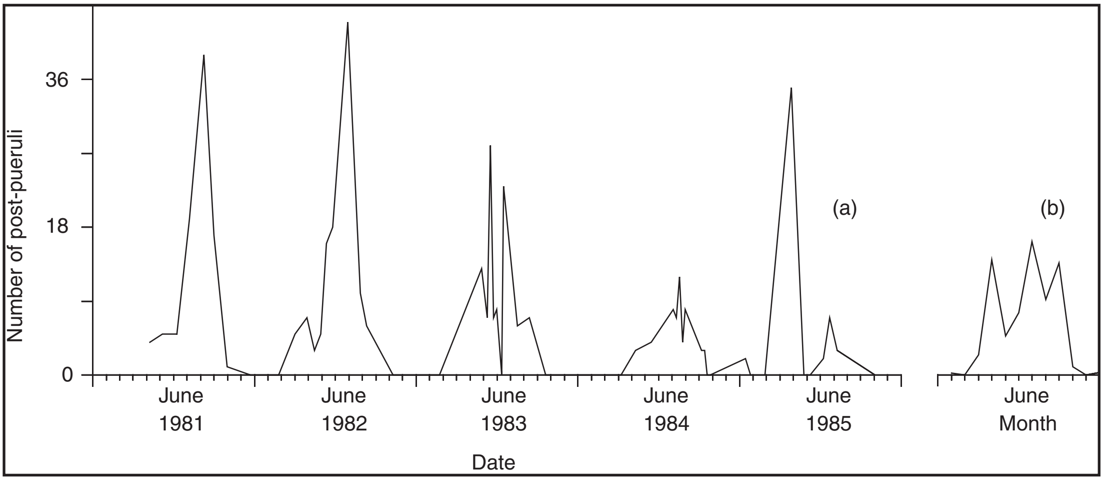

Figure 7. Timing of settlement of the ornate rock lobster *P. ornatus* on wharf piles in Cairns harbour, Australia during 1981–1985 (a) and the average for all years (b).

Juvenile habitat preferences

In situ

The habitat preferences of juvenile ornate rock lobsters in Torres Strait were examined during intensive diver surveys in 1992–93 and also during annual population surveys. Small juveniles (<20 mm CL) were observed throughout the Torres Strait fishing grounds, at all depths surveyed (3–21 m) and invariably co-habitating with sub-adult (1+ and 2+ year-old) lobsters (Dennis et al. 1997). Small *P. ornatus* juveniles are invariably found sheltering individually in solution holes in the seabed. Most shelters have some cover of macroalgae, mainly *Sargassum* sp. or *Padina* sp. Juveniles occupy shelters with dimensions positively correlated

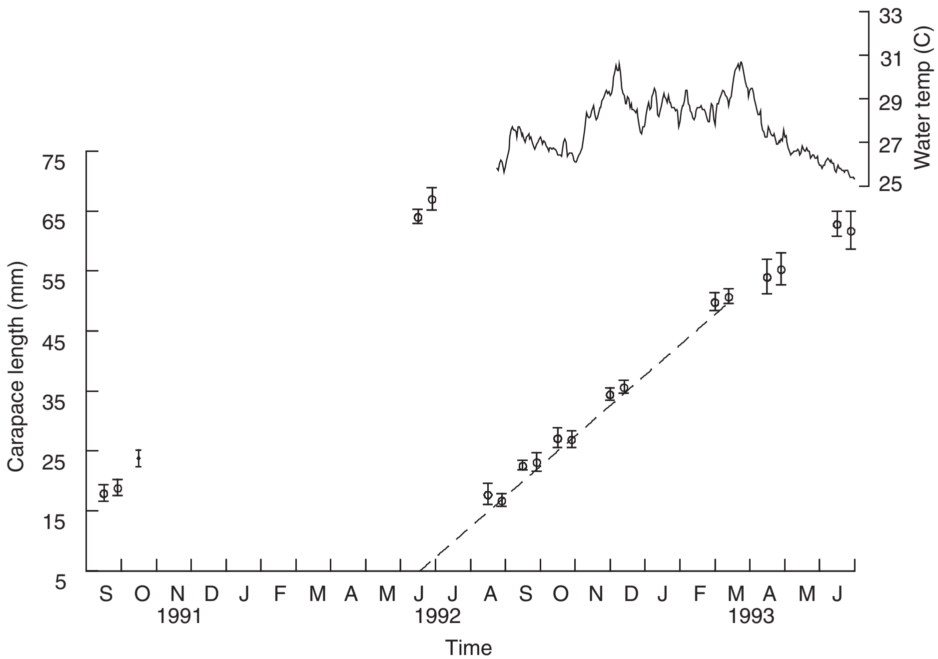

Figure 8. Early growth of *P. ornatus* in the field in northwest Torres Strait during September 1991 to June 1993. Dashed line shows extrapolation used to estimate mean settlement date in 1992.

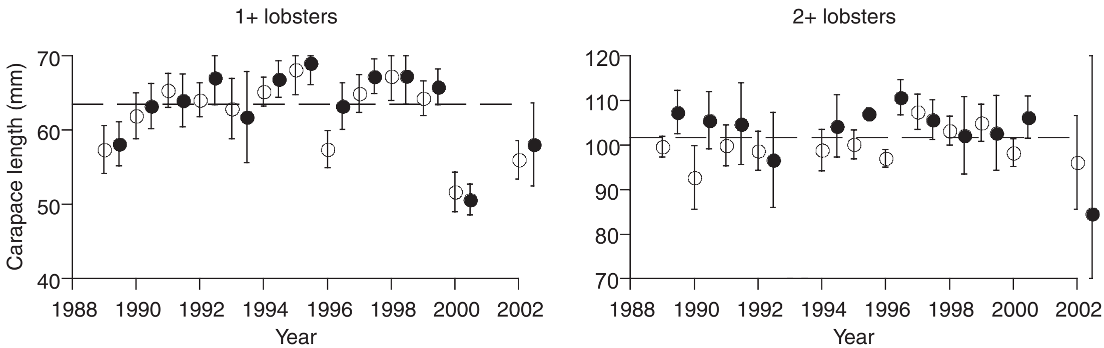

Figure 9. Mean size of male (circles) and female (filled circles) 1+ year-old and 2+ year-old lobsters collected between 1989 and 2002, showing temporal differences in mean size of the two-year classes. Error bars are standard errors. The 14-year averages are indicated by the dashed lines.

with their own body dimensions (Fig. 10), presumably serving to reduce the risk of predation.

The results of this research highlight why conventional collectors used for other spiny lobsters are not successful for *P. ornatus*, in Torres Strait at least. The *in situ* habitat of pueruli has not been identified in Torres Strait and remains an important research issue, particularly with the recent interest in ongrowing this species.

Aquarium experiment

The shelter preferences of newly-settled ornate rock lobsters was studied using surviving pueruli from plankton samples collected in the northwest Coral Sea during May 1997. The pueruli were released into an aquarium containing artificial shelters to examine the shelter preferences of newly-settled, and subsequently, first instar juvenile lobsters. The artificial shelters consisted of crevices, holes, and caves cut into two blocks (400 × 200 × 40 mm) of aerated concrete (Hebel®), one laid horizontally and the other placed vertically; as well as bare sand. Two crevices, 6 mm wide by 15 mm deep, were cut across the top and bottom of each block. A total of 210 holes with diameters of 5 mm, 10 mm and 15 mm were drilled, in groups of three, into the horizontal and vertical blocks. Half of these were drilled to a depth of 15 mm and half to 30 mm. Horizontal cave shelters were created by drilling fifteen 25 mm holes into the front edge of the horizontal block. The sand on the bottom of the aquarium was level with the centre of, and filled the floor of, these caves. A further fifteen 25 mm holes were drilled into the top edge of the vertical block.

A total of 54 pueruli were placed in the aquarium during the 26 days of observation, but 12 subsequently died and were removed. The locations of all pueruli and first instar juveniles were recorded each morning. Shelter preferences were tested using Pearson Chi-square tests on one-way or two-way contingency tables of observation counts pooled over the 26 days. The shelters chosen by the pueruli and first instar juveniles were recorded on 297 and 600 occasions respectively. Both stages showed significant ($p<0.001$) preference for hole shelters over cave, crevice or sand shelters. No lobsters sheltered in 5 mm holes. Pueruli showed no significant ($p = 0.630$) preference for 10 mm or 15 mm hole shelters but juveniles significantly ($p<0.001$) preferred 15 mm over 10 mm holes. Both pueruli and juveniles showed significant preference ($p<0.001$ and $p = 0.002$, respectively) for deeper hole shelters, although for both stages this preference was less obvious for the 10 mm diameter holes compared with the 15 mm hole shelters. In the hole and crevice shelters, the pueruli and juveniles showed no significant preference ($p = 0.319$ and 0.689 respectively) for vertical or horizontal orientation. On 36 occasions, pueruli were found buried in sand with their antennae lying on the sand surface, but no juveniles were seen to do this.

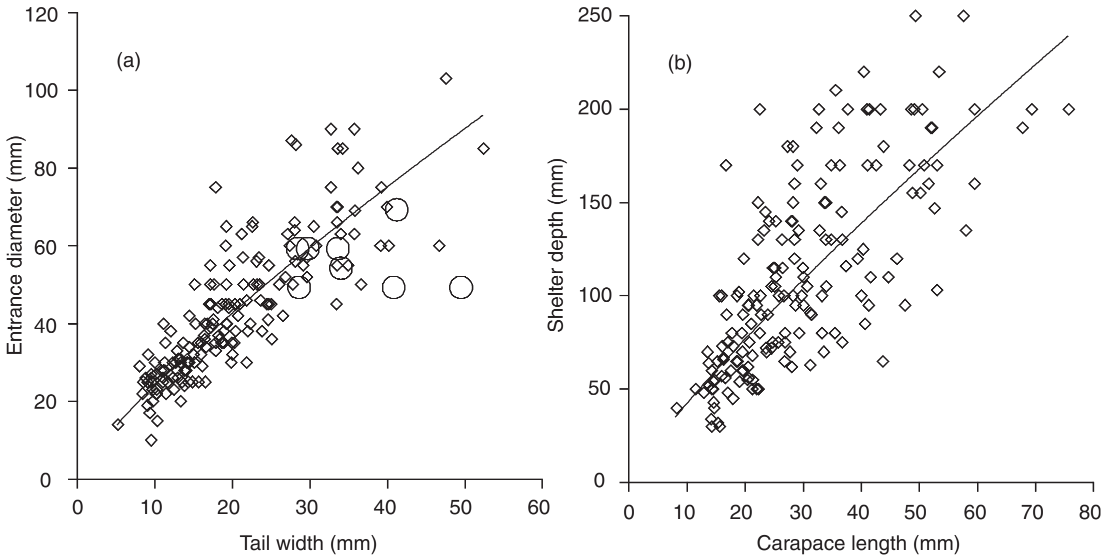

Figure 10(a) and 10(b). (from Dennis et al. 1997). Relationships of: (a) shelter entrance diameter versus tail width; and (b) shelter depth versus carapace length for *Panulirus ornatus* juveniles collected in northwest Torres Strait, Australia. ◊, holes; ○, crevices.

The preference for holes over sand or crevice and cave shelters shown by newly-settled juvenile *P. ornatus* compared well with shelter preferences shown by wild lobsters in Torres Strait (Dennis et al. 1997) (Fig. 11). However, the habitat of wild pueruli in Torres Strait has not been documented. The observed ability of pueruli to shelter in bare sand presumably serves to reduce the risk of predation while pueruli are searching for more suitable habitat.

Growth

In situ

The growth of *P. ornatus* in Torres Strait has been estimated using tag-recapture (Phillips et al. 1992) and modal progression methods (Skewes et al. 1997, Dennis et al. 1997). The growth rate (5.2 mm CL mn^{-1}) of *P. ornatus* in Torres Strait is the highest recorded for any spiny lobster in the first year of benthic life. This is likely due to the combination of: predominant warm water temperatures (>280C), low densities and low competition (63 ha^{-1}; Dennis et al. 1997) and availability of shelter and food throughout Torres Strait. In Torres Strait between 10–20% of *P. ornatus* juveniles reach 75 mm CL (minimum harvestable size until 2002) within one year after settlement (Fig. 12). Within Torres Strait there are spatial differences in growth with lobsters in the northwest being about 10% larger (mm CL) than those in the SE (Fig. 12).

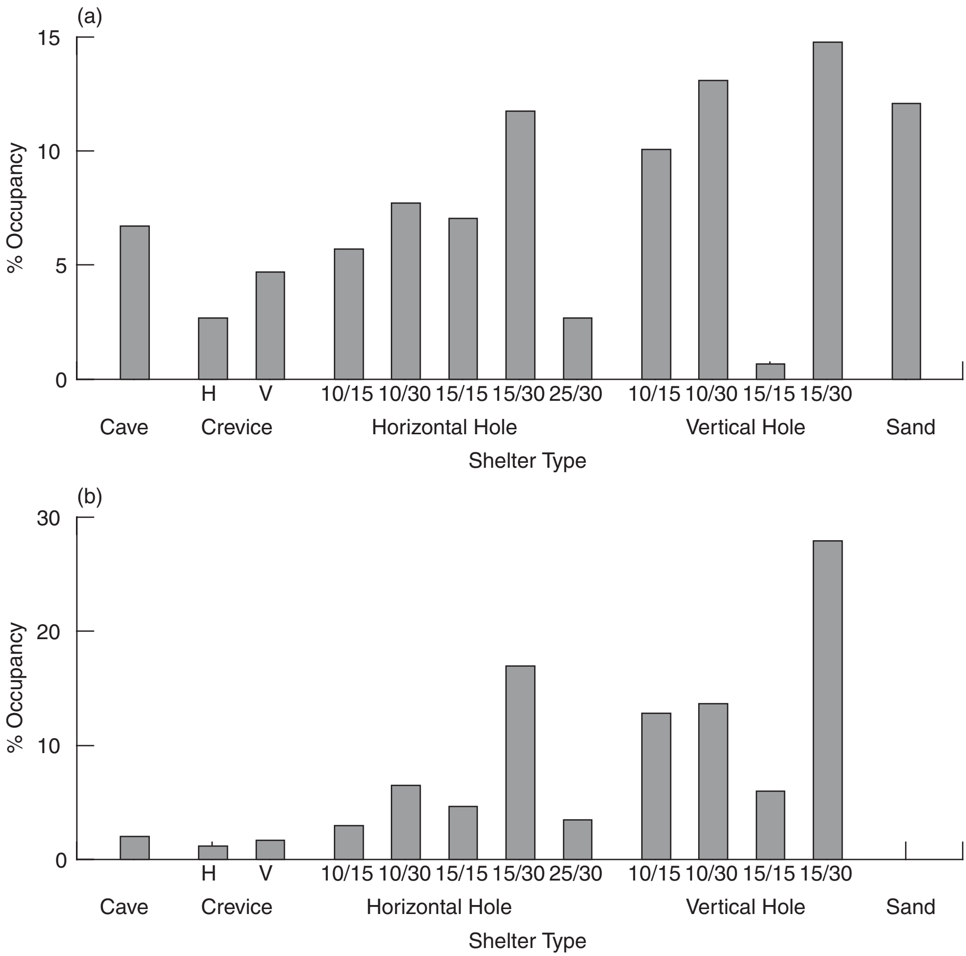

Figure 11. (from Dennis and Pitcher 2001). Percent occupancy by newly-settled (a) and first instar juvenile (b) *P. ornatus* in several shelter types offered in an aquarium. Bar labels indicate horizontal (H) or vertical (V) orientation and the diameter and depth of hole shelters in mm (for example, 10/15 corresponds to 10 mm diameter and 15 mm depth).

Laboratory

Following the finding that growth of *P. ornatus* varies spatially in Torres Strait, a laboratory study was conducted to determine the impact of temperature on growth. The laboratory trials showed that juveniles grew 31% faster (mm CL week-1) at 30°C compared with growth at 26°C (Fig. 13). This information is also pertinent to proposed grow-out of this species in Torres Strait.

The laboratory trials conducted at the Cleveland Marine Laboratories provided data to estimate growth of this species throughout a broad size range. The increase in carapace length at moult (moult increment) for different size lobsters (between 7 mm and 160 mm carapace length) is generally explained by a quadratic function, which shows a maximum at about 85 mm carapace length (Fig. 13), whilst the relationship between moult interval (days) and carapace length is well explained as a linear function. Although linear growth rate (mm/week) data is extremely variable for different sized lobsters and highlights inherent growth variability, growth is generally fastest for lobsters between 30 mm and 50 mm carapace length (Fig. 13). Growth rate in terms of weight showed even greater variability, although the increase at moult was generally greatest for lobsters between 100 mm and 120 mm carapace length. Consideration of optimal growth rates will also be important in assessing the viability of grow-out of this species in Torres Strait.

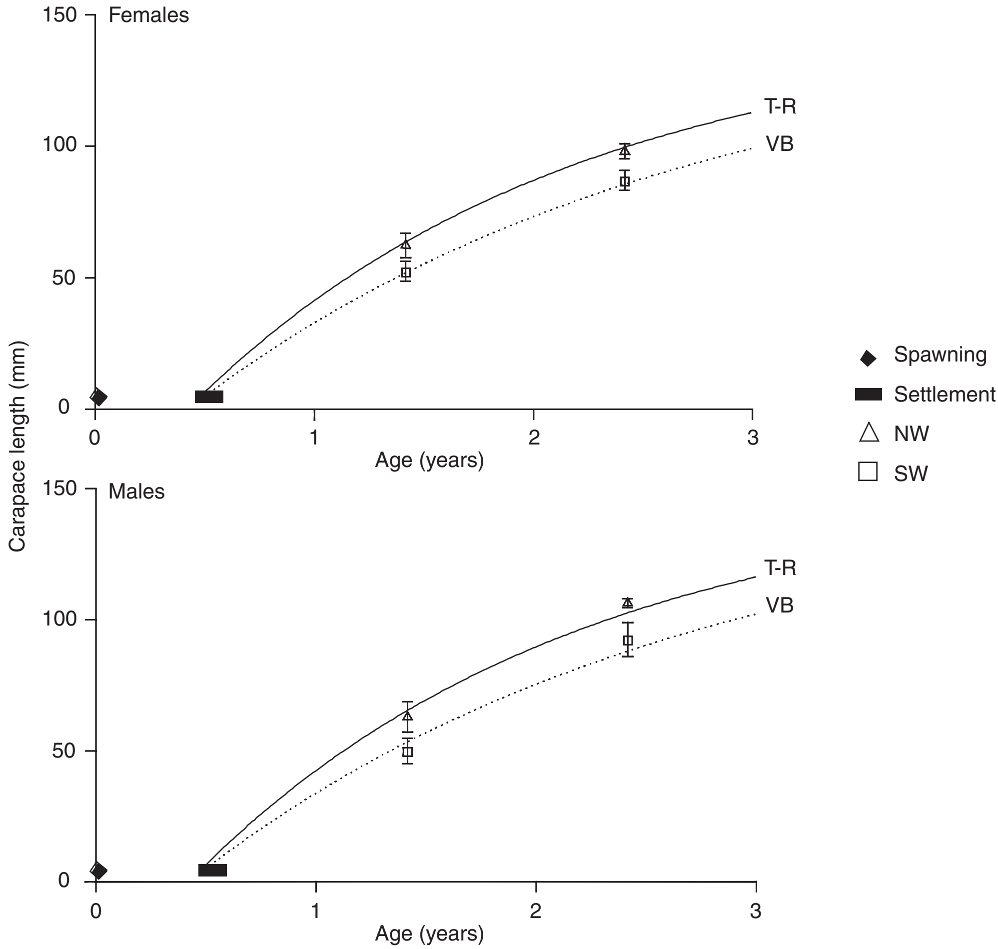

Figure 12. (from Skewes et al. 1997). Growth curves modelled from field tag–recapture growth curves (T–R) for *P. ornatus* (Phillips et al. 1992), the von Bertalanffy growth curve with the coefficient k = 0.44 yr $^{-1}$ (VB) and the average size of the 1+ and 2+ lobsters (with 95% C.I.) in the northwest and southeast zones of Torres Strait from modal analysis of size frequencies from population surveys.

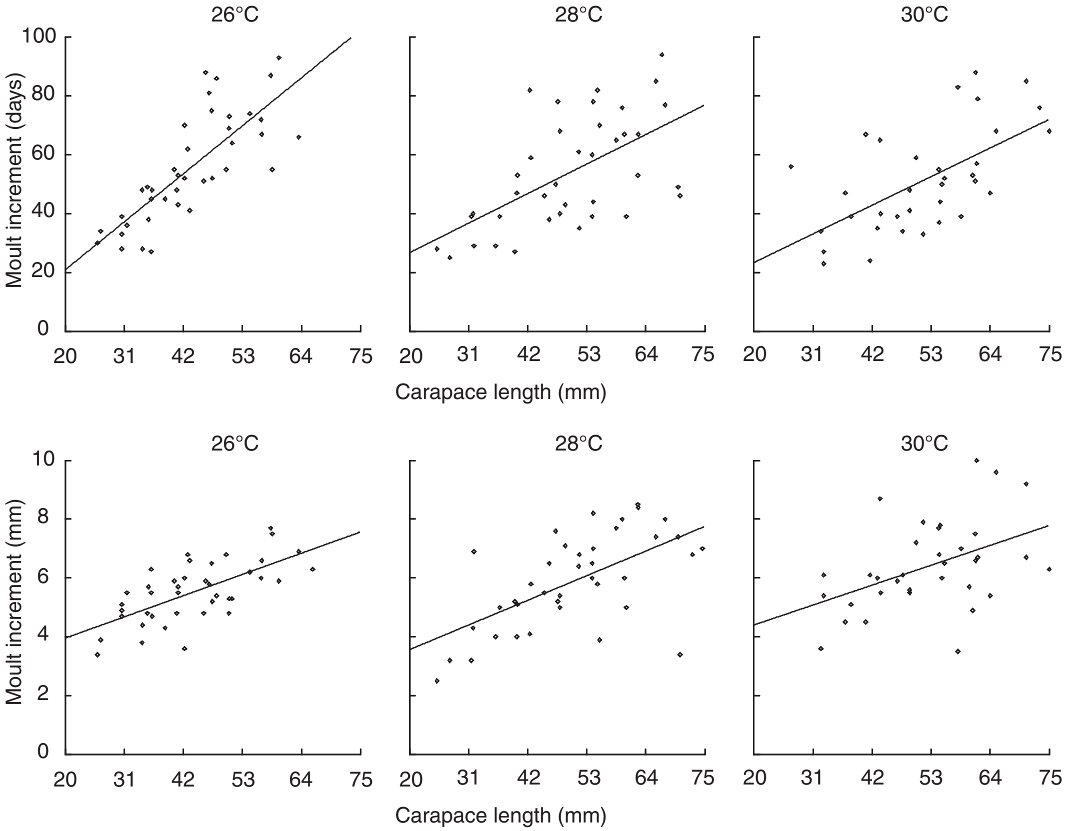

Figure 13. (from Dennis et al. 1997). Relationships of moult interval and moult increment versus carapace length for *P. ornatus* juveniles reared at 26°C, 28°C and 30°C in the laboratory. Linear regression lines are shown.

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Modelling the transport of tropical spiny lobster larvae *Panulirus ornatus* in east Australian waters

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Introduction

The panuliridae all have very long pelagic larval phases, during which the larvae could be transported great distances by ocean currents. Oceanic dispersal of three Australian spiny lobster populations has been studied in some detail using computer simulation and satellite estimates of ocean circulation. These models are still only crude representations of what happens in reality, but nevertheless, do provide valuable insight into the important question of where the settling puerulus stage (or seed lobsters) have come from.

Methods

Early-stage lobster larvae are competent swimmers but most of their swimming effort is believed to be directed at achieving a desired depth depending on the time of day. Hence, we can model their horizontal transport by assuming they move at the velocity of the water at an appropriate depth depending on the time of day. As the larvae get older, the depth range of their diurnal excursions changes, and for some species, there is evidence of a dependence on the state of the moon and how rough the sea-state is. It is also possible that variations in the depth of the thermocline could affect vertical migration, but the available data are too few for general statements to be made. The same is true, to an even greater extent, for the vertical distribution of the prey items upon which the larvae are feeding.

We model the vertical migration of *P. ornatus* larvae by distinguishing just three age classes, and just three depth strata that they occupy at various times: a near-surface layer (0–10m), a middle layer (20–50m) and a deep layer (50–100m) (Fig. 1).

To estimate the velocity of the water at these three depths, we use a combination of a simple wind-driven time-dependent Ekman-layer model, satellite altimeter observations of perturbations of sea level, and a global hydrodynamic model for estimates of the time-mean water velocity (see Griffin et al. 2001).

Results

The model has been run for the *P. ornatus* stock in the Coral Sea for the years 1995 through to 2000, with 2000 individuals being tracked for each year class (Pitcher et al. 2004). The hatch locations of these individuals are distributed throughout the known local range of the species such that the real regional intensity of egg production is approximately represented. Figure 2 shows the tracks of those larvae that settled in the Cape York region of northeast Queensland by the end of each modelled year.

Figure 3 shows the tracks of all the larvae that were hatched from the Cape York region and their predicted fate and destination. These results show that the puerulus settling (in the model) to the main Australian sector of the fishery came from a wide geographic range. The progeny of the adult lobsters within the fishery were also widely distributed in the model. The influence of the semi-permanent gyral circulation between Australia and Papua is clear, as is the influence of the bifurcation of the South Equatorial Current where it hits Australia at about 15°S. While it must be remembered that the model does not include many processes affecting survival of larvae, these results do give insight into the transport processes governing the movement of those larvae that do survive.

Discussion

The South China Sea is similar in some ways to the Coral Sea, but of course it is different in others. It would be surprising if understanding of the dispersal of larvae in one of these ocean basins would not provide valuable insight into the dispersal of the same species' larvae in the other ocean basin.

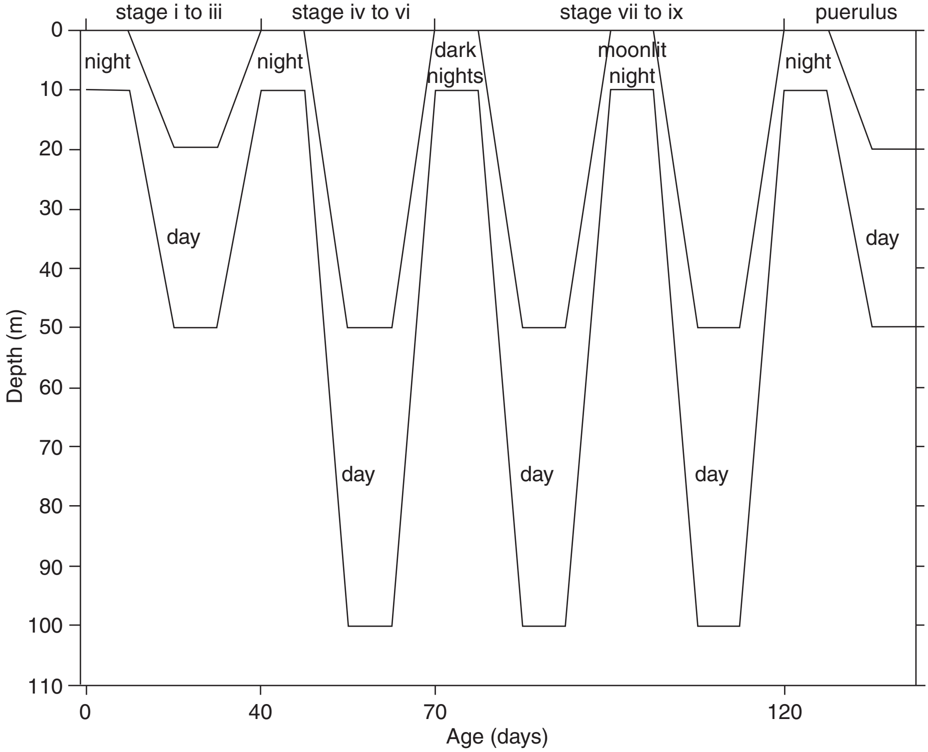

Figure 1. Modelled vertical migration behaviour of *P. ornatus* larvae.

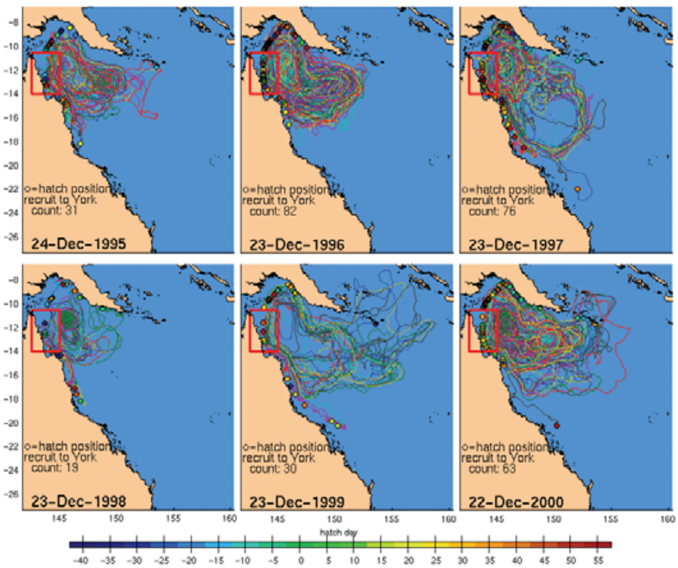

Figure 2. Tracks of larvae settling in the York region (red box). Hatch locations are shown as small circles, coloured to indicate the day-of-year of hatching. Individual tracks are randomly coloured to help distinguish individuals.

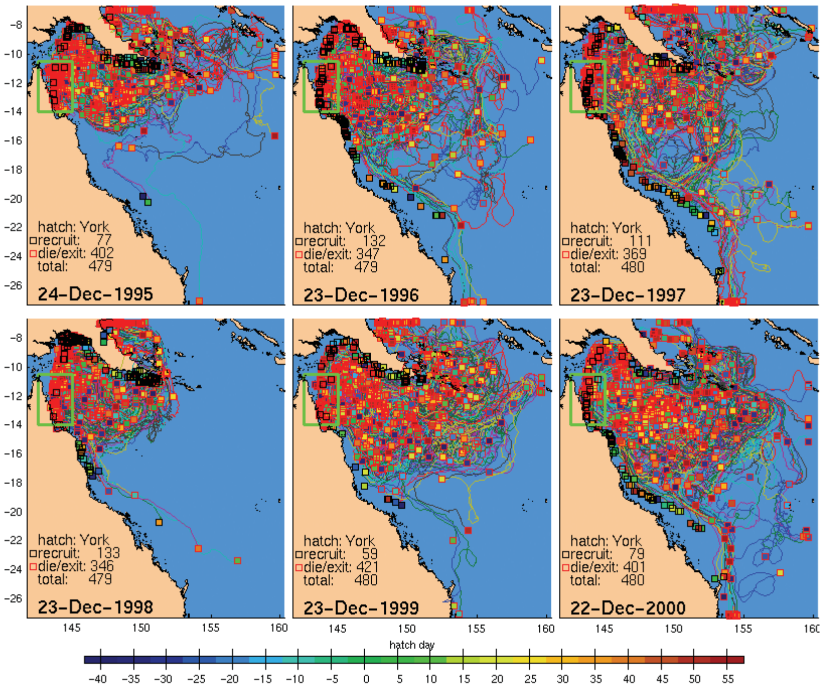

Figure 3. Tracks of larvae that were hatched in the York region (green box). Terminal locations are shown as small squares, red in the case of dieing or exiting the model domain, black in the case of successfully settling. The colour within the symbol indicates the day-of-year of hatching.

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Some Typical Hydrodynamic Characteristics of the Sea of Vietnam and Adjacent Waters

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Introduction

Bien Dong (South China Sea; SCS) is a semi-enclosed tropical sea located between China and Vietnam to the north and west, the Philippines islands to the east, Borneo to the southeast, and Indonesia to the south. The total area is about 3.5 million square kilometres. SCS is connected to the East China Sea by the Taiwan Strait, to the Pacific by the Luzon Strait, to the Sulu Sea by the Mindoro Strait, to the Java Sea by the Gasper and Karimanta Straits, and to the Indian Ocean by the Strait of Malacca. The complex topography includes a continental shelf in the north and the south-southwest, a deep shaped basin in the center and many reef islands and underwater plateaus.

This paper focusses on some hydrodynamic characteristics of the sea of Vietnam and adjacent waters. Climate, geometry size, geographical location, characteristics of bottom topography, coastline and the capacity of water exchange of the region with adjacent waters are briefly discussed.

Materials

Information in the paper is derived mainly from the results of investigation, analysis of data in databases held at the Institute of Oceanography and other studies carried out in Vietnam in recent years.

Main hydrologic and dynamic characteristics

Characteristics of interaction between land waters and ocean

Land water impacts: Land waters have noticeable impact only on surface waters, that is, those less than 100 m deep. The degree of impact of land waters on coastal waters can be gauged by changes in salinity. The strongest impact is normally seen in the northwestern parts of the Gulf of Tonkin and the northeastern parts of the Gulf of Thailand in all four seasons. The waters adjacent to the Mekong River estuary are strongly impacted in summer-autumn, but negligibly (in comparison with impact from offshore waters of SCS) in the winter-spring. The coastal waters of south Central Vietnam are impacted only slightly by land waters and then only in autumn and the impact is negligible in other seasons.

Moving trend of water masses: In the Gulf of Tonkin, there have been severe conflicts of land water masses, which have resulted in low salinity, while offshore waters in SCS have shown positive salinity anomalies. On average, there is at least one large and a number of smaller cyclone events each year, which impact on the Gulf of Tonkin. Land waters tend to move southward along the western coast of the gulf, penetrating deeply into the coastal waters and continental shelf of the central part of Vietnam. The currents along the coast from Gulf of Tonkin carry pink-brown sediments originating from the Red River and these can be observed as far south as Quang Ngai waters (15°N). Offshore waters flow easterly and thus affect, primarily, only the northern part of the gulf. The coastal current on the western side of the gulf always moves from the north to the south.

Each year, one average size cyclone impacts on the Gulf of Thailand in the winter-spring and typically one anticyclone in summer-autumn. The water exchange through the gulf mouth is weak in winter-spring, but relatively strong in summer-autumn. The water exchange between the Mekong River and the northeastern region of the Gulf of Thailand occurs relatively early in summer-autumn.

Main water movements in offshore region

Based on calculation of geotrophic currents by Vo and Tong (2001), two main geotrophic eddies are recognised in the SCS: a clockwise (cyclonic) current in the northwestern and northern parts, and an anticlockwise (anticyclonic) current in the central and southwestern parts, with diverged and converged zones in the central and southwestern parts of SCS, respectively (Figure 1). The current speed in the summer, in general, is higher than in spring and autumn and most of the water between 0–500 m show the movement of these two currents. The authors also observed that the southward current along the coast of the central part of Vietnam exists throughout the year and has the strongest intensity in autumn-winter, the smallest intensity in spring-summer and decreases in intensity in the northern central part of Vietnam.

There is a strong upwelling in the center of the northern gyre and this exists throughout the entire year. It occurs from the offshore in the winter and moves close to the coast of central Vietnam in spring-summer. The front zone, or the adjoining zone, between the clockwise current in northwestern and northern parts of SCS and the anticlockwise current in the central and southern parts of SCS exists all year long, stretching from the continental shelf of central and southern Vietnam to western Luzon and Bashi Strait.

Coastal cold current in Vietnam

On the basis of analysis on the thermal and saline fields, Chevey and Carton (1939) discovered a cold current under the surface, which moves southward along the coast and could reach to Cape Varella (Dai Lanh, 12°40′N). It exists not only in the winter but also in the summer. Based on hydrodynamical modelling calculation as well as analysis of thermal-saline data by sections quartering to the coast in the southern central part of Vietnam, Hoang (1977) has defined the spatial scale and size of this current system. Nguyen (1990) concluded, based on hydrological data analysis for the whole sea, that the cold and strong current in the narrow coastal zone of Vietnam has been affected by the current system exchanging through Luzon Strait and Taiwan. Based on the analysis of data obtained by the Nha Trang Institute of Oceanography, Bui and Nguyen (2001) reported a zone of converged warm and cold water extending across the South China Sea from Nha Trang to Manila.

On the basis of reviewing and analysing the materials and data from the database, Vo and Dang (2002) defined the southward cold current along the coast of central Vietnam, which exists in both winter and summer, creating a low temperature region in this coastal zone. In the summer this current can reach as far south as Phan Rang (11°30′N), meeting the warm current from the south and causing the phenomenon of current separation (moving offshore). In winter, this current can reach Binh Thuan (10°30′N). The existence of this current clearly affects the marine ecosystems (plankton). Some plankton originating from the Gulf of Tonkin has been discovered in the Phan Rang and Phan Thiet regions. It also affects the biodiversity and nutrient resources of the coastal area of central Vietnam.

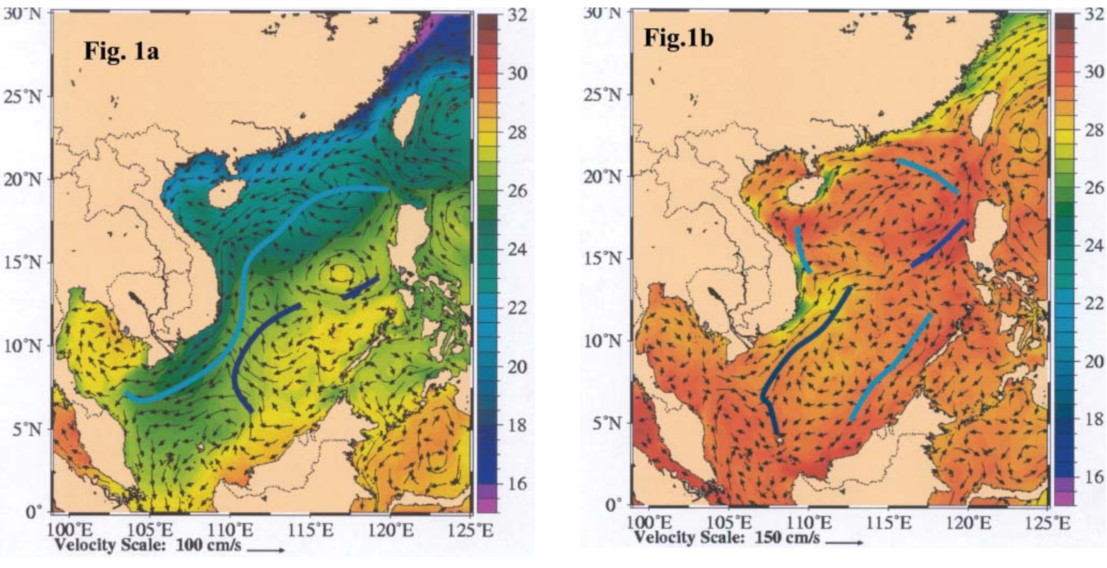

Figure 1. The geotrophic current (cm/s) at the surface of the South China Sea in winter (Fig. 1a) and summer (Fig. 1b). Diverged zone shown as light blue lines and converged zone shown as dark blue lines. Water temperature is indicated by the colour gradient, and current speed and direction by size of arrow.

The phenomenon of strong upwelling in SCS and along the coast of southern central Vietnam

Based on limited data sets, some cool pools (signal of upwelling areas) were detected in the SCS (Chu et al. 1998). Nitani (1970) earlier reported the appearance of a cool pool northwest of Luzon. More recent analysis of TOPEX/POSEIDON and NOAA satellite remote sensing data has shown the existence of five upwelling areas in the central coast region of the SCS. The phenomenon of upwelling along the coast of southern central Vietnam was first discovered in 1959–1960 by the American mixed investigation program (NAGA) on the sea of south Vietnam and the Gulf of Thailand. In this program, the phenomenon of upwelling was revealed by analysis of the distribution and structure of hydrological factors such as temperature, salinity and seawater density. It was recognised that in the coastal area and continental shelf of southern central Vietnam there existed centers of low temperature, high salinity and seawater density caused by waters upwelling from deep layers. These observations were reported by Wyrtki (1961), Robinson (1961) and LaFond (1961).

Up to now there have been only three large-scale investigation programs related to the study area. They are the investigations of NAGA program (1959–1960), investigations of Thuan Hai–Minh Hai program (1978–1980) and investigations of KT03-05 project (1991–1995). Among them, the first two were mixed investigations; only the third one was specialised on the phenomenon of upwelling in the coastal area of southern central Vietnam. In the latter investigation, the physical factors (meteorology, hydrology and current), hydrochemistry, geochemistry, hydrobiology and some specific ecological effects were studied, in addition to orient studies on characteristics of geometry and physics of upwelling as well as their ecological consequences. However, it needs to be recognised that because of financial, equipment and technological constraints, detailed investigations could only be carried out at some narrow regions in the center of the strongest upwelling in the coastal areas of Ninh Thuan and north Binh Thuan.

In parallel with the above-mentioned investigations, the characteristics of the phenomenon of upwelling in the coastal area and continental shelf of south Vietnam has been studied at the Institute of Oceanography (Nha Trang, Vietnam) by data analysis and calculation of numerical hydrodynamical modelling.

The upwelling phenomenon in coastal central Vietnam

The upwelling occurs along the entire coastal zone and continental shelf of southern central Vietnam, from Ninh Thuan to Binh Dinh provinces. The center — that is the strongest upwelling — is observed in the coastal waters and the continental shelf from Ninh Thuan to the northern part of Binh Thuan provinces (Fig. 2). Here the cold water from the deep-reaching Western Boundary Current is upwelled from a depth horizon of 125 m.

The upwelling varies strongly with the season but also during synoptic periods (Hu et al. 2001). However, it can be found every year from May to September, most strongly, in June, July and August. The synoptic periods may last from 2–3 days and up to 8–9 days according to the synoptic periods of the southwest monsoon. In the center of the strongest upwelling during synoptic events, the vertical upwelling velocity can reach 10^{-1}–10^{-2} cm/s, whereas the seasonal variations can reach 10^{-3}–10^{-4} cm/s (Fig. 3). The upwelling velocity is always largest at its starting horizon (125 m), decreasing to zero at sea surface. However, even at the sea surface the upwelling can cause temperature and salinity anomalies of 4°C and 1.0 psu, respectively.

Associated current patterns in the upwelling area

The strongest upwelling area coincides with the position where the two current systems meet, that is the deep-reaching counter-wind Western Boundary Current originating from the Luzon Strait intrusion and the monsoon-driven current from the Sunda Shelf (Hu et al. 2000; Isobe and Namba 2001). The latter has been modified by entrainment of coastal water, especially from the Cuu Long estuary. At their convergence point, both of these current systems have a tendency to orientate seaward, creating favourable conditions for the development of upwelling in near-shore sea waters.

General conclusions

- The effect of land waters on water exchange, material exchange and sedimentation are very important processes impacting on the sea of Vietnam.
- Surveys and monitoring stations (for long-term assessment) are required to be made at the sections crossing the mouths of Tonkin Gulf, Thailand Gulf and some other regions for more accurate and quantitative measurement of effects.
- Quantitative measurement of the input from Red River and Mekong River is a research priority.
- The southward cold current in coastal area of central Vietnam plays a very important role in the ecosystem, biodiversity, resources and oceanographic

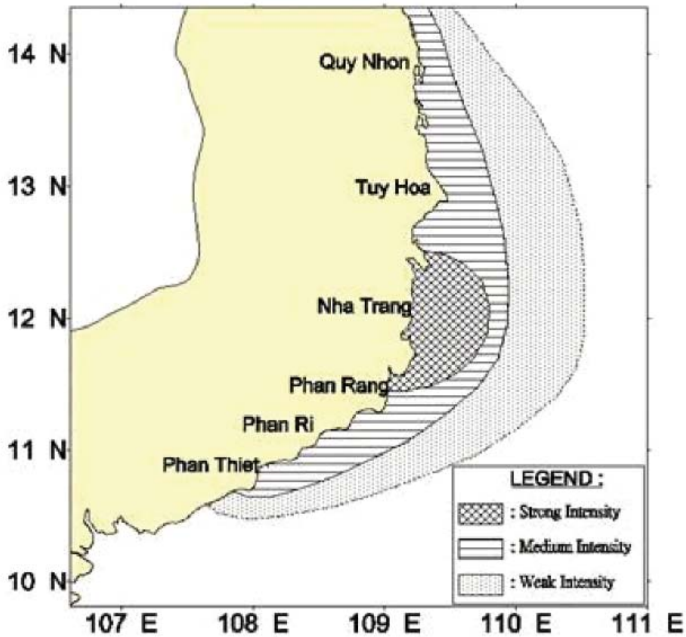

Figure 2. Intensity zoning of the upwelling off the south Vietnamese coast. Derived from hydrographic measurements taken over the last decade (Long, Pers. comm.).

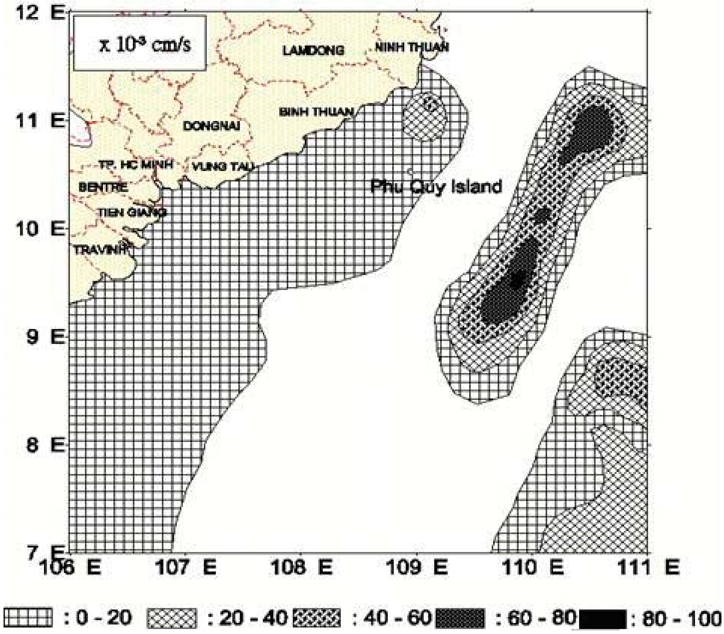

Figure 3. Summer upwelling velocity off south Vietnam in 10^{-3} cm/s calculated with a simplified stationary model for climatological mean conditions.

dynamics of the region. It is necessary to implement detailed studies to define the boundaries, front zone, temporal and spatial events and their impacts on processes in the SCS.

- Research on seasonal geotrophic eddies in SCS is vital for a better understanding of the dynamic and hydrological events taking place.
- The phenomenon of strong upwelling in the coastal area of central Vietnam and offshore SCS significantly affects the physical and biological processes of the area. There is a critical research need for detailed studies on all processes affecting the SCS, particularly mechanisms and formation processes, intensity, temporal and spatial occurrence and impacts of long period meteorological change.

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Larval Dispersal Simulation of the Spiny Lobster, *Panulirus ornatus*, in the Philippines Using Merged Altimeter-derived Absolute Dynamic Topographies

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Introduction

SPINY lobsters are widely distributed in the Philippines but the most valued species are *Panulirus ornatus* and *P. versicolor*. A survey conducted by Juinio-Meñez and Dantis (1996) on the lobster distribution and fishery in the Philippines show that *P. ornatus* distribution vary with the seasons (Fig. 1). It is found in northeastern Luzon during March to May. In Pangasinan and La Union, and in Zamboanga del Sur/Sibugay, it was reported to occur throughout the year except during the peak months of the southwest monsoon season. In eastern Samar, *P. ornatus* is present during the southwest monsoon season. However, in a few areas, ornatus was reported to occur throughout the year (for example in southeast Mindanao).

Reports of occurrences of juveniles from the survey by Juinio-Menez and Dantis (1996) highlights two areas — Cagayan/Isabela area and southwest Mindanao (Fig. 2). Recent reports also indicate the presence of large numbers of *P. ornatus* juveniles in Guian, eastern Samas and Sibugay. It is unclear why juveniles are observed in larger numbers here compared with other areas where adults are also found. Given that *P. ornatus* has the longest planktonic larval duration (PLD) at eight months, it is reasonable to assume that the dispersal of *P. ornatus* larvae will be influenced by large-scale current systems in offshore waters. The objective of this study is to simulate the long range dispersal of *P. ornatus* larvae using dynamic topographies — which reflects the current systems in offshore areas — and to determine likely

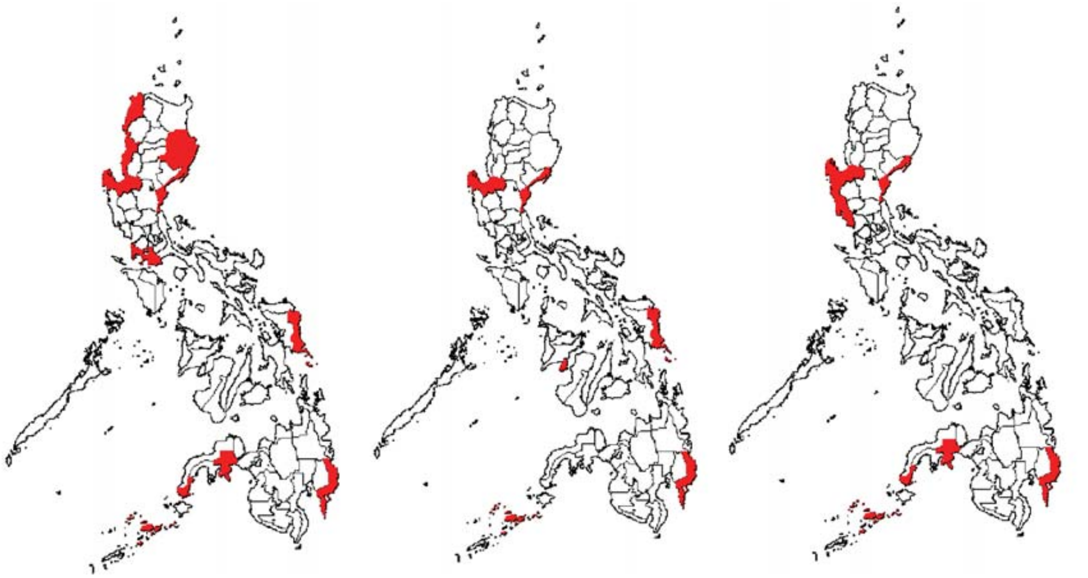

Figure 1. Distribution of *P. ornatus* during spring monsoon transition (left), southwest monsoon (middle) and northeast monsoon (right). (Redrawn from Juinio-Meñez and Dantis, 1996).

sources of these juveniles. Areas where egg-bearing lobsters are found are shown in Figure 3. Of the areas identified, the most persistent is in the northeast tip of Luzon, Palawan, and eastern Samar and eastern Mindanao. These areas will be used as the source areas for dispersed larvae in the simulations.

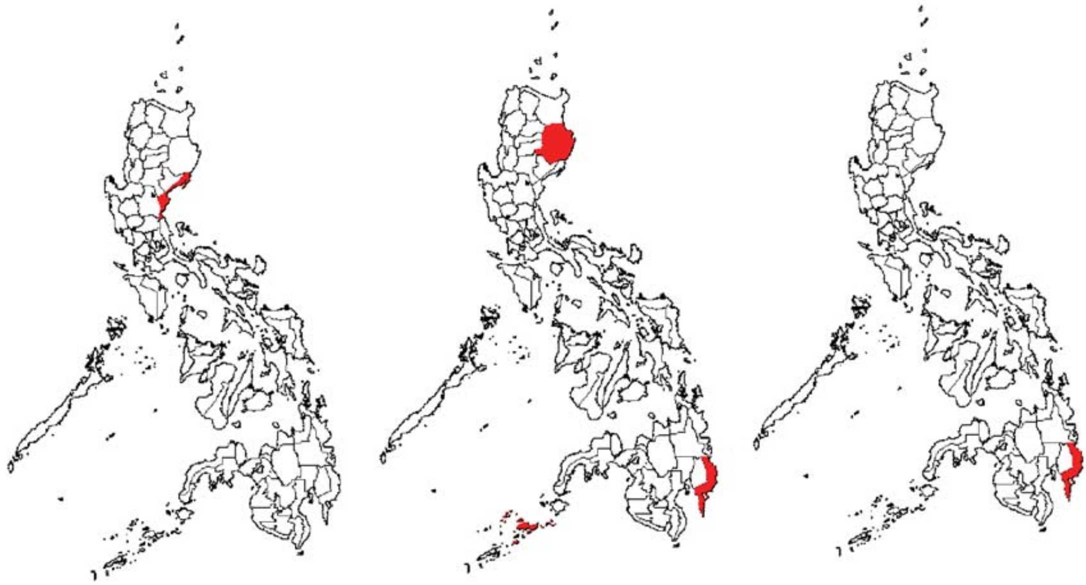

Figure 2. Distribution of *P. ornatus* juveniles during January (left), May (middle) and October (right). (Redrawn from Juinio-Meñez and Dantis 1996).

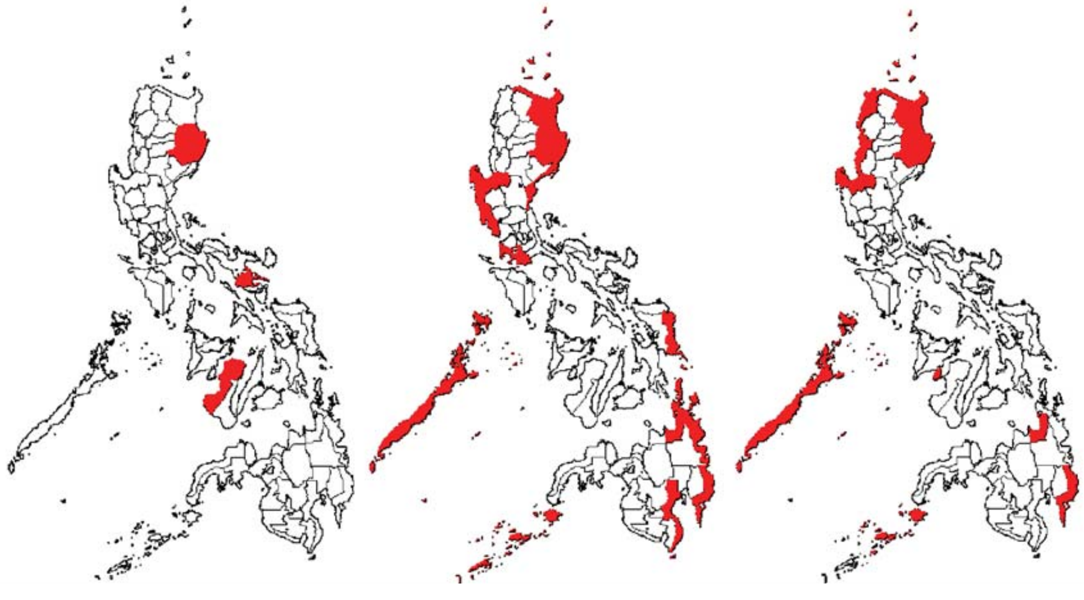

Figure 3. Distribution of egg-bearing females during January (left), May (middle) and August (right). (Redrawn from Juinio-Meñez and Dantis).

Methods

Absolute dynamic topography data with a resolution of 1/3° longitude × 1/3° latitude were obtained from Ssalto/Duacs merged altimetry data (http://www.aviso.cls.fr/html/ portail/general/welcome_uk.php3). The data obtained was for the year 2002 at intervals of seven days. The geostrophic velocities were calculated from the dynamic topographies using the following equations:

$$u = \frac{g}{f}\frac{\partial h}{\partial y}$$

$$v = \frac{g}{f}\frac{\partial h}{\partial x}$$

where $g = 9.8\ \mathrm{ms}^{-1}$
$f = 2\,\Omega \sin\phi$;
$\Omega = 7.292 \times 10^{-5}\ \mathrm{s}^{-1}$
ϕ = latitude

An example of dynamic topography and derived geostrophic velocities for January 5, 2002 is shown in Figure 4. The derived velocity field shows the major features of the circulation in the south China Sea, Sulu Sea, and the Philippine Sea in the Pacific.

The dispersal of larvae was simulated using a Lagrangian model adapted from Polovina et al. (1996). The advection velocities were obtained from the dynamic topographies. Larvae were represented as passive particles and their position (x,y) over time was tracked using the following equations:

$$x_{t+\Delta t} = x_t + \frac{\left[u_{x,y,t}\Delta t + \varepsilon\sqrt{D\Delta t}\right]}{\cos(y_t)}$$

$$y_{t+\Delta t} = y_t + \left[v_{x,y,t}\Delta t + \varepsilon\sqrt{D\Delta t}\right]$$

where t = time;
x,y = larval position in degrees longitude and latitude,
u,v = components of velocity;
ε = randomly generated number ranging from –1 to 1;
D = eddy difussion rate (m^2/s);

Each simulation starts by specifying the release point and time of release including the number of particles. All particles were released simultaneously from the source points and allowed to run for a period similar to the planktonic larval duration of *P. ornatus*, which is eight months.

The selection of the source areas for the larvae and timing of release were based on distributions of egg-bearing lobsters (Fig. 4). In northeastern Luzon, egg-bearing adults were found throughout the year, while in eastern Samar and eastern Mindanao, egg-bearing individuals were found mainly during the southwest monsoon season. Along the south China Sea, the source areas used was Palawan during the southwest Monsoon and Zambales during the spring monsoon transition (April-May).

Results and Discussion

The relative frequencies of the simulated larvae released off the northeast coast of Luzon are shown in Figure 5. At this latitude, the Kuroshio dominates the offshore circulation and results in the dominant

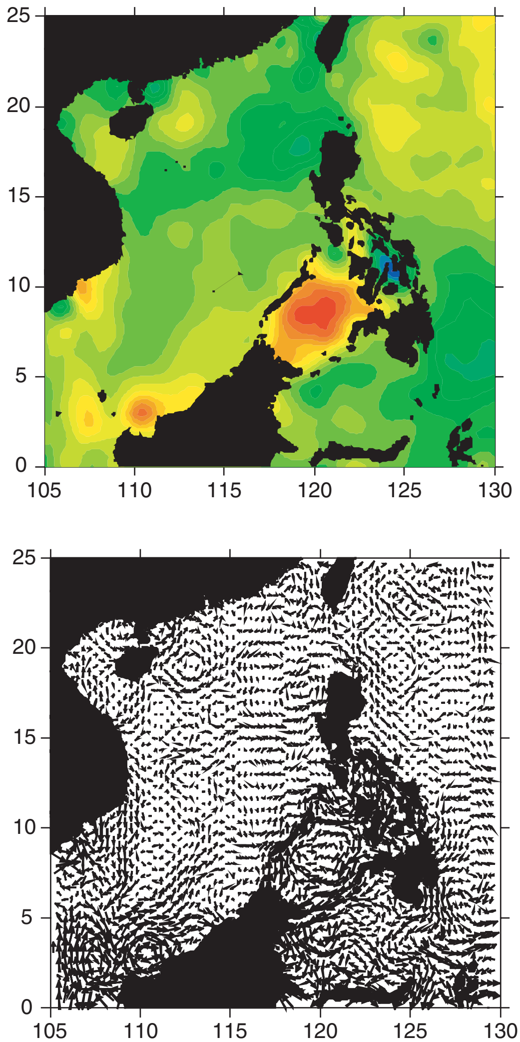

Figure 4. Merged altimeter-derived absolute dynamic topography representing the period January 1–7, 2002 (top) and derived geostrophic velocities (bottom).

transport of the larvae further north to Taiwan. The general dispersal pattern is similar for all seasons except that during the spring monsoon transition (April-May), more larvae are advected into the south China Sea. Dispersal along the path of the Kuroshio is strongest during the northeast monsoon season.

Further south, off Mindanao, the direction of dispersal is towards the south because of the prevailing Mindanao Current (Fig. 6). During the spring monsoon transition, larvae were dispersed into the interior of the Sulawesi Sea. The advection into the Sulawesi Sea is reduced once the southwest monsoon prevails and most of the larvae are transported eastward into the North Equatorial Counter Current (NECC).

In the south China Sea, the current systems are not as persistent compared with the Pacific. Currents are mostly seasonal, although in some areas persistent flow can be observed such as in the western coast of

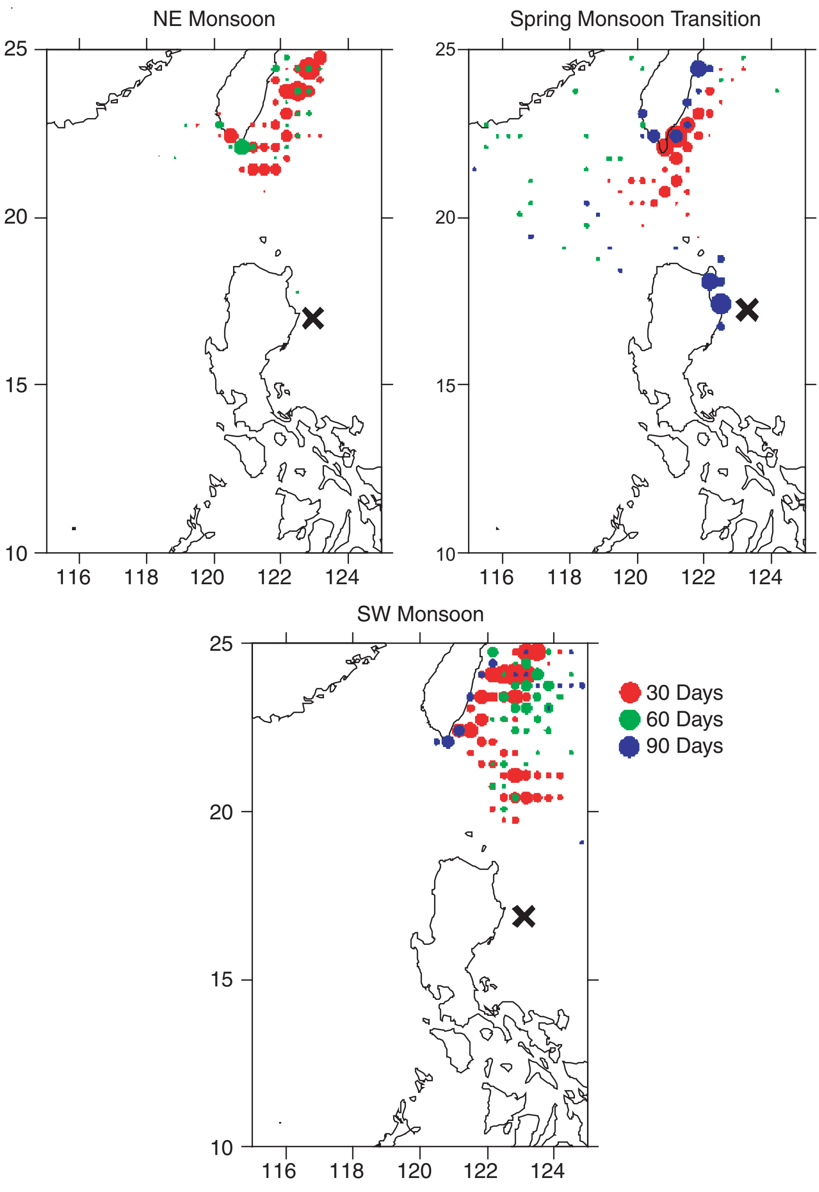

Figure 5. Relative frequency of simulated larvae released from northeastern Luzon for different seasons.

Luzon. However, during the April-May period, wind speeds of the south China Sea are at their weakest and since the south China Sea circulation is predominantly wind-driven (Hu et al. 2000), current velocities are also weak. The simulation results for larvae released from western Luzon during April (Fig. 7) are not unreasonable given the prevailing conditions in the south China Sea at this time.

A similar pattern was observed for larvae released from northwest Palawan, but because currents were flowing inshore, all the larvae were trapped at the coast after a few days (Fig. 8). Since the velocities were derived from dynamic topographies, sometimes, the flow is not constrained to be parallel to solid boundaries. This will be accounted for in future simulations. However, if released during the southwest monsoon, the simulated larvae were advected into the Visayas seas through the Mindoro Strait (Fig. 9).

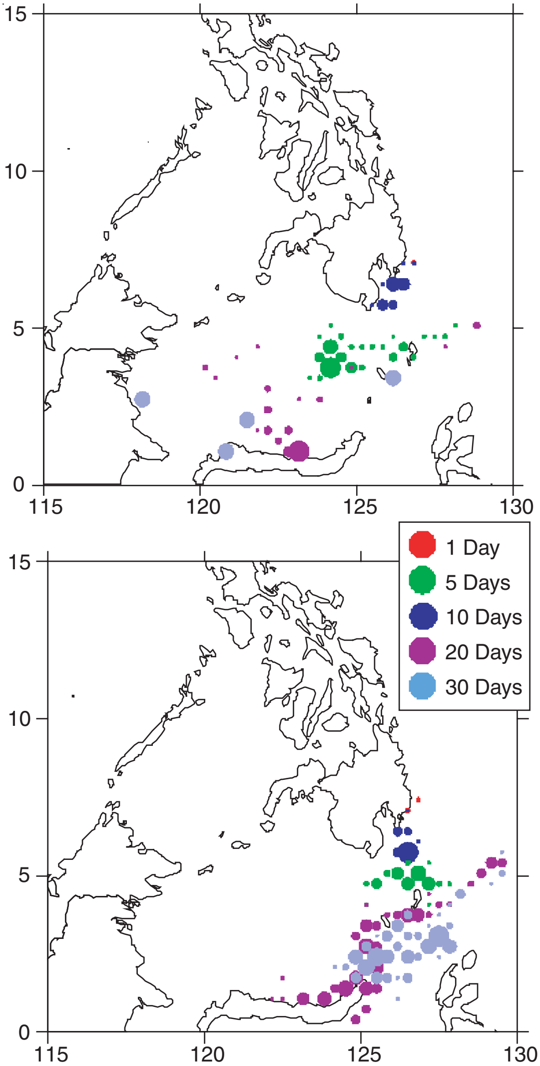

Figure 6. Relative frequencies of simulated larvae released from eastern Mindanao during the spring monsoon transition (top) and southwest monsoon (bottom).

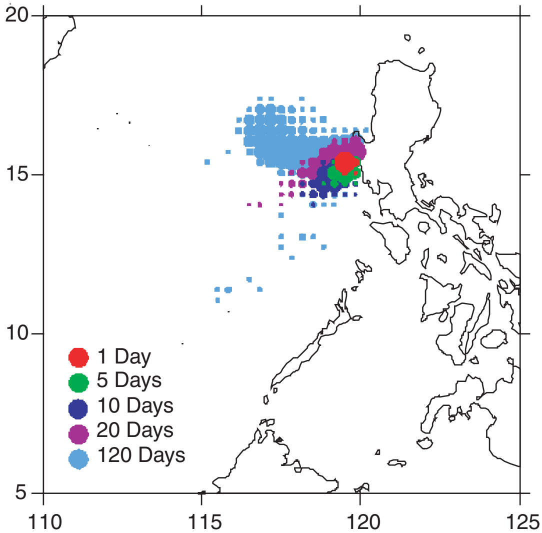

Figure 7. Relative frequencies of simulated larvae released from the western coast of Luzon during the southwest monsoon.

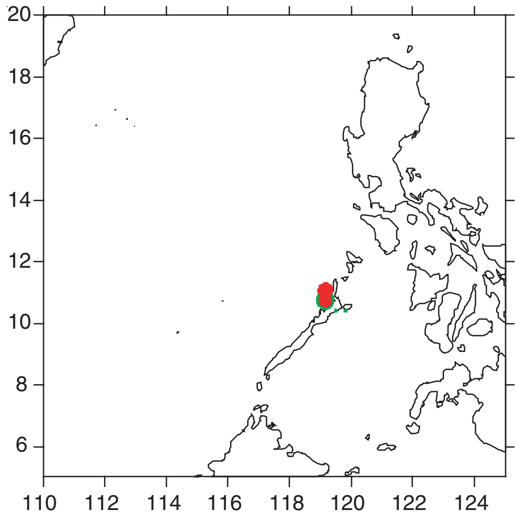

Figure 8. Relative frequencies of simulated larvae released off northwestern Palawan during the spring monsoon transition and southwest monsoon (bottom).

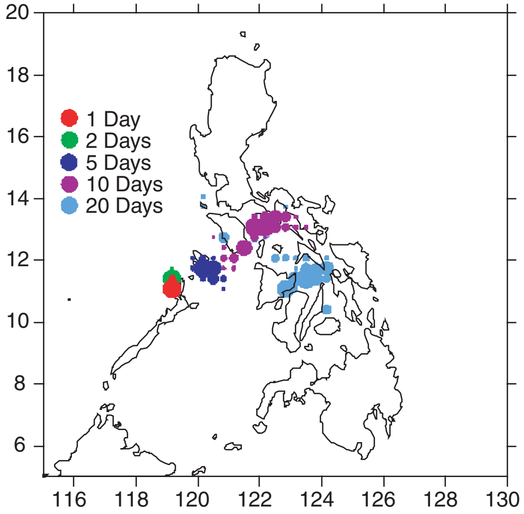

Figure 9. Relative frequencies of simulated larvae released off northwestern Palawan during the SW Monsoon.

Summary and Conclusions

The results presented here are an initial attempt to simulate the dispersal of a long-range dispersal organism such as *P. ornatus*. The use of the dynamic topographies provides reasonable velocity fields in offshore areas, but they were prone to errors closer to land and along narrow channels typical in the internal seas of the Philippines. Dispersal in the Pacific side is dominated by the western boundary currents (for example, Kuroshio and Mindanao current), while in the south China Sea diffusive effects are stronger, most likely due to weaker and highly variable wind-driven flow.

The velocities fields used in this study may have some limitations, particularly in the narrow passages between narrow islands. The coarse resolution and the averaging may contaminate dynamic topographies in the neighboring basin if the islands separating the basins are narrower than the data resolution. This is apparent along the western coast of Palawan.

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Session IV

TOWARDS MORE SUSTAINABLE LOBSTER AQUACULTURE

Do Huu Hoang

Shell remains of whole green mussels fed to lobsters.

Combined Culture of Mussel: A Tool for Providing Live Feed and Improving Environmental Quality for Lobster Aquaculture in Vietnam

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Figure 1. Green mussel *Perna virdis* grown on rope lines and suspended next to lobster cages to improve environmental conditions and provide a cleaner source of feed for lobsters.

THE survival rate of lobsters fed on cultured mussel was higher than those traditionally fed on fresh fish (by-catch), while the growth rate of lobsters was the same for both feeding systems (Fig. 2). However, lobsters fed on mussel were healthier than those fed by-catch. The authors estimated that if the lobsters were raised for 18 months (instead of 14 months in the current experiment), total weight of lobsters fed on mussel would be 100 kg/cage of 100 individuals. This figure was almost double the total weight of lobsters fed by-catch, which was only 60 kg/cage of 100 individuals at the same site the previous year (2002). This indicates that live mussel was a good feed for lobsters. If this system of mussel and lobster co-culture was adopted, it would play an important role in reducing the demand for by-catch for feeding lobsters and also have the beneficial effects of removing organic pollutants (uneaten and waste feed and nutrient excretions) from the surrounding water.

Environmental quality around the cages of combined culture of lobsters and mussel was improved compared with that where lobsters were cultured in the traditional way. Concentrations of organic matter in the deep water and in the sediment reduced by 83% and 63% respectively at the site of the combined culture. These reductions were more rapid than those at the site of the culture without mussels (namely, 65% and 44% respectively). Microorganisms in the sediment decreased markedly by 94% for Fecal coliform and 76% for *Vibrio* at the site of combined culture, but increased by 23% and 91% respectively at the site of traditional culture.

The above findings are still only preliminary and await a detailed statistical analysis. Moreover, experiments must be repeated and validated so as to determine the optimal mussel stocking capacity for the lobster culture area, the filter feeding capacity of the mussels and to provide robust data on the productivity benefits (survival, growth rate, FCR, etc) of co-culturing mussels and lobsters. Such data are needed to optimise the culture system, reduce the amount of investment needed to be made by the lobster farmer and to reduce overall risk to the farmer. However, the results of the present study are very encouraging and suggest that mussel and lobster co-culture is a good solution to both protect the capture fishery (reduce demand for by-catch) and to reduce the negative environmental impacts of culturing lobsters based on feeding only fishery by-catch.

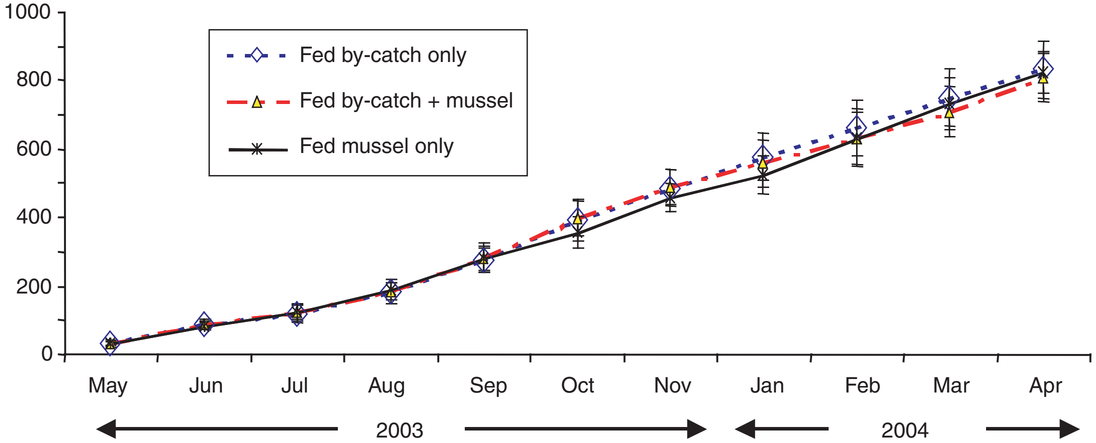

Figure 2. Comparative growth of lobsters fed by-catch only (◇), by-catch and mussel (△) or mussel only (*) during a 12-month growout period at Xuan Tu village, Nha Trang.

Key Issues for Sustaining Aquaculture Production of the Spiny Lobster, *Panulirus ornatus*, in Vietnam

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Introduction

In recent years, there has been considerable interest in increasing the production of spiny lobsters through the capture and culture of puerulus larvae (Booth et al. 1999; Jeffs and James 2001; Phillips and Melville-Smith 2001; Mills et al. 2004). The basic premise is that survival of puerulus larvae can be increased greatly in culture compared with survival in the wild and, provided catches of puerulus remain a small proportion of those available, this form of aquaculture can add substantial production without jeopardising replenishment of the natural population (Hair et al. 2002). In addition to the industry that has been operating in Vietnam growing-out *Panulirus ornatus* since the late 1990s (Tuan et al. 2000; Williams et al. 2002), enterprises are also being developed in Australia and New Zealand for other species of spiny (or rock) lobsters.

The rapid growth of the aquaculture industry for *P. ornatus* in Vietnam provides an example of the potential gains that can be made through the capture and culture of puerulus larvae. However, it is clear that the industry there needs to address several key issues to be sustainable. The purpose of this paper is to identify and briefly discuss these issues.

Key issues

Source of puerulus larvae

An essential part of sustainable management of the spiny lobster aquaculture industry in Vietnam is to identify the population that supplies the puerulus larvae, and to safeguard sufficient wild broodstock to ensure an abundant supply of eggs each year. A population genetics study of *P. ornatus* in the south China Sea is required to determine the distribution of the adults supplying the puerulus, and whether they all occur within the territorial waters of Vietnam. If not, Vietnam will need to develop co-operative arrangements with neighbouring countries to manage the population to ensure a continued supply of pueruli. The extended larval duration of *P. ornatus* (ca. 5 months), increases the likelihood that the distribution of the population supplying the larvae covers a large area.

Population size and exploitation rate

Once the distribution of the population supplying puerulus larvae of *P. ornatus* to Vietnam is identified, the numbers of breeding adults, and their rate of exploitation, need to be estimated. The fishing sectors and ports accounting for the catch also need to be identified. If these assessments show that the number of adults is below that required for regular replenishment, regulations will need to be introduced to rebuild and safeguard spawning biomass.

Serious consideration may need to be given to applying a different paradigm to management of spiny lobsters in Vietnam — one which gives priority to protecting the adults and harvesting the juveniles for growout in aquaculture. Nevertheless, this should be done in a way that takes into account the need to spread the benefits of the resource as widely as possible — legislation preventing all harvest of adults would discriminate against fishers not able to take part in capture and culture enterprises, and for this reason a limited, controlled catch of adults may be necessary. However, if it is not possible to monitor or regulate the number of adults caught, it would be better to prohibit the catch of adults to provide a regular supply of pueruli for growout in aquaculture.

Spatial and temporal variation in abundance of puerulus larvae

Safeguarding sufficient spawning biomass to produce an abundant supply of eggs is no guarantee that there will be a constant supply of puerulus larvae. On the contrary, the vagaries of life in the plankton and variation in local currents will mean that the abundance of pueruli changes from year to year. This has been well documented for spiny lobster fisheries in western Australia (Phillips et al. 2000) and Cuba (Cruz et al. 1995). However, data on larval supply from other fisheries for spiny lobsters show that some areas consistently receive more pueruli than others, regardless of the numbers settling. Identifying the spatial distribution of puerulus larvae of *P. ornatus* in Vietnam will help to structure the industry by equipping people in those areas to catch pueruli and distribute them to growers elsewhere.

Identifying the spatial variation of puerulus larvae will involve establishing a long-term monitoring program using replicated collections at sites located at prescribed distances apart along the coast of Vietnam where pueruli of *P. ornatus* have been recorded. Such a sampling programme will also provide an index of annual abundance. Such settlement indices are used in Australia and Cuba to determine annual year class strength and subsequent catch rates of spiny lobsters (Caputi et al. 1995; Cruz et al. 1995; Phillips et al. 2000). Provided there is also a strong correlation between abundance of puerulus larvae and the numbers of *P. ornatus* that recruit to the fished population, the settlement index could be used to determine the sustainable catch of pueruli, and the subsequent catch of adults 2–3 years later.

There are two main consequences for the industry of spatial and temporal variation in abundance of pueruli. First, opportunities for catching puerulus larvae will be better in some parts of the country than others. Second, there will need to be limits on the catch of pueruli to ensure sustainability, and these limits will vary depending on the strength of the year class.

What percentage of pueruli are being collected?

The monitoring programme to determine the spatial and temporal variation in abundance of puerulus larvae will establish where they occur, and how many there are, each year. However, it is also important to monitor the catches of pueruli to ascertain whether they are excessive or sustainable. A system requiring fishers for puerulus larvae to provide complete reports of their catches needs to be implemented urgently. This system needs to be in place by the time the first results from the monitoring programme of spatial and temporal abundance of pueruli are in hand.

Determining how many pueruli should be caught

Assessing whether catches of puerulus larvae of *P. ornatus* are sustainable will depend on knowing their rate of survival between settlement and recruitment to the adult population. Once this has been estimated robustly, the sustainable catch of pueruli can be calculated as the number settling minus the number needed to provide enough adults to replenish egg supply (and perhaps also to provide for a limited fishery for adults in situations where it can be regulated adequately). For several other species of spiny lobster, <5% of pueruli survive the first benthic year (Herrnkind and Butler 1994; Butler et al. 1997; Phillips and Melville-Smith, 2001; Mills et al. 2004). Until data for the rate of survival of *P. ornatus* following settlement are available from Vietnam, it is reasonable to assume that the rate may be similar. However, reliable estimates based on well-designed field experiments will enable fine-tuned exploitation of pueruli, and maximum benefit to the aquaculture industry.

Hair et al. (2002) provide a hypothetical example of the benefits of capture and culture of *P. ornatus* in Vietnam based on an arbitrary annual supply of 100 million pueruli, 5% survival in the wild, and higher rates of survival in captivity. In their analysis, capture of 2 million pueruli for culture would reduce the numbers surviving the first benthic year in the wild from 5.0 to 4.9 million for that year class. However, if 90% of the captured individuals survived during growout (which is reported to occur regularly by the growers, and for other species of spiny lobsters, for example, Thomas et al. 2003), then there would be production of an additional 1.8 million spiny lobsters that year. Even under a scenario of poor (20%) survival in culture, an additional 0.3 million individuals would be produced.

Implications of low rates of settlement of pueruli

An important management measure is necessary due to the low rates of survival following settlement: there should be a prohibition on catching juveniles that have settled successfully to natural benthic habitats. These individuals have run the gauntlet of intense predation associated with settlement and have a good chance of recruiting to the adult population. Intense exploitation of such juveniles, which is currently occurring due to the very high prices paid by aquaculture enterprises, is comparable to other forms of fishing and can be expected to have severe consequences for replenishment of spawning biomass.

One way of preventing fishing for larger settled juveniles would be to apply a very small (that is, puerulus or immediate post-settlement stage) size limit to individuals collected for aquaculture, and to impose heavy penalties for use of any individuals above this size or not collected by nets or purpose-built collectors designed to catch pueruli. This poses a number of issues about how to recognise individuals caught as puerulus larvae throughout the growout cycle.

In Tasmania, Australia, a more proactive measure has been introduced to ensure that sufficient pueruli survive to replenish the fishery. There, enterprises licensed to capture puerulus larvae of *Jasus edwardsii* are required to return the 5% expected to survive naturally, plus an additional 20%, to the wild (D. Mills, Pers. comm.). These individuals are returned at a larger size after a period of culture to ensure even greater rates of survival.

Does aquaculture help increase egg production?

In Vietnam, *P. ornatus* is often grownout to a size of 1 kg. This allows females to produce one batch of eggs. The suggestion has been made that this practice could help replenish the wild population. However, many of the growout pens are located in bays where the larvae are likely to be retained in the immediate area. Also, the water quality in such places is different from the areas where developing larvae are released by spawning adults associated with offshore habitats. Consideration needs to be given to locating some, if not all, growout pens at sites where larvae produced by females in captivity have a greater chance of contributing to the next year class of pueruli. Research on the proportion of females spawning in pens, and local current regimes, is needed to assess whether such regulations are likely to be beneficial.

Impact of spiny lobster farming on other fisheries resources

Although the effects of aquaculture of spiny lobsters on other fisheries resources is outside the scope of this workshop, this issue also needs to be addressed urgently as the potential benefit of the industry will be diminished greatly if the food needed by the spiny lobsters is collected in a way that damages other fisheries. This is particularly the case where animals are removed from inshore nursery habitats, such as sea grass beds. Catches from these areas often contain juveniles of other valuable species and such practices will severely affect the yield-per-recruit for other fisheries. The solution to this problem is to develop a formulated diet for spiny lobsters based to the greatest extent possible on terrestrial sources of protein.

Conclusions

The grow-out of juvenile *P. ornatus* in Vietnam has created a substantial industry, and delivered new and lucrative livelihoods to coastal communities. However, urgent attention must now be paid to identifying: (1) the population of spiny lobsters that supplies the puerulus larvae; and (2) the sustainable rates of catch for both pueruli and adults. Recommended catch rates can be expected to change from year to year due to environmental factors affecting settlement that are beyond the control of managers. Assessments also need to be made about how to use the spiny lobster resource in the best interests of the country. Given the considerable gains in survival of juveniles that is possible through aquaculture, leading to substantial increases in production, reductions in the catch of adults may need to be considered to promote the supply of puerulus larvae for growout. Provided that the juveniles can be reared in ways that do not have adverse effects on other species, this may lead to a new paradigm for fishing for spiny lobsters, by way of exploiting the juveniles and safeguarding the adults.

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Synthesis of Workshop Discussion

Topic 1: What information exists on the fishing pressure of lobsters, particularly *P. ornatus,* the abundance and location of adults and seed lobsters in the South China Sea?

A Small amount of reliable data are available. For her PhD studies, Dr Nguyen Bich Thuy compiled catch size data on four species of lobsters caught in Vietnamese waters over three survey times that spanned 10 years (Table 1). For all four species, the data show a marked decrease in the catch size of the lobsters at each successive survey time.

Seasonality of the catch is thought to be more a reflection of whether fishers were able to go out to catch (e.g. effect of typhoons and monsoon season) rather than abundance of lobsters at different times. A further difficulty is the marketing of lobster catches across country borders. For example, Sabah lobster data can include lobsters caught and 'imported' from Indonesian or Philippino waters. Some information exists on juvenile abundance but very little on phyllosoma abundance/distribution. There is a critical need to gather reliable data on the fishing pressure (species, quantity, locality, season and gender of catch) that tropical SCS lobsters are subjected to.

Very little data are available on stock assessment. In Vietnam, sub-adult *P. ornatus* were fished along the central coast 10 or more years ago, particularly when lobsters migrated from coastal to deeper waters for spawning. Traditional fishing grounds for *P. ornatus* are waters off the southern provinces of Ninh Thuan and Binh Thuan. There was *P. ornatus* fishing in the Spratley Island group from 1990–1994, but this stopped when demand for live lobster product made it unprofitable to sell frozen product from the Spratley Islands. *P. ornatus* are widely distributed on the continental shelf of the southern part of the South China Sea but no systematic stock assessment appears to have been carried out. Data on lobster catch per unit effort (CPUE), both of fished adults and collected

Table 1. Size of four species of lobsters caught in Vietnamese waters for survey years of 1984, 1989 and 1994 (Thuy, 1999)

Year	Percentage of catch in each size class (carapace length)					
	<40 mm	40–49 mm	50–59 mm	60–69 mm	70–79 mm	>80 mm
			P. stimpsoni			
1984	0	3	34	33	18	12
1989	1	7	49	31	3	9
1994	8	58	19	13	1	1
			P. longipes			
1984	0	6	13	27	23	31
1989	0	22	41	26	5	6
1994	14	34	25	20	5	2
	Percentage of catch in each size class (carapace length)					
	<50 mm	50–59 mm	60–69 mm	70–79 mm	80–89 mm	>90 mm
			P. homarus			
1984	0	9	20	21	21	29
1989	3	21	34	29	6	7
1994	58	26	11	1	3	2
	Percentage of catch in each size class (carapace length)					
	<40 mm	40–59 mm	60–79 mm	80–99 mm	100–119 mm	>120 mm
			P. ornatus			
1984	0	3	10	16	25	46
1989	0	8	62	21	5	4
1994	11	22	32	8	8	19

seed, would be a valuable index of fishing pressure and sustainability but the difficulty of obtaining accurate data is recognised. Such data would help to set realistic maximum sustainable yield quotas for the fishery — for fished adults and collected seed. While the increasing unit price for the collected lobster seed in Vietnam may indicate a lower CPUE, this need not always be the case. For example, because of the growing affluence of China, demand for sea cucumbers has gone up, and this has resulted in a substantial increase in the unit price of local cultured products even though the supply has increased greatly. Lobsters could show similar trends with demand for seed forcing up seed price while CPUE remains unchanged. It would be a useful exercise to calculate the number of spawning lobster stock needed to sustain the seed collection in Vietnam, which is estimated to be about 3,500,000 seed in 2003–4, and the number of seed needed for overall natural stock replenishment. The primary questions here are 'where are the adults?' And, 'are they adequately protected/managed to sustain the supply of seed?' What is the population structure of *P. ornatus* in the SCS? Is Vietnam a source or sink within a metapopulation?"

Topic 2: What conditions favour good catches of swimming/settling pueruli?

During the lobster settlement season in Vietnam (November to April), fishers use the light net trap method to catch swimming lobster seed every night. High powered light (2000 w) is placed on the surface at the net opening to attract pueruli. The moon phase is not so important, rather, the best catches occur immediately after storms and rough weather, which are thought by local fishers to result in the seed being dislodged from the bottom and into the water column. Another possibility is that onshore storm winds push pueruli entrained in the nearshore southward current towards the shore. *P. ornatus* pueruli are caught along the whole central coast of Vietnam, from Lang Co (Thua Thien-Hue Province) in the north (16.5ºN) to Ca Na (Binh Thuan Province) in the south (11ºN). However, the number of pueruli caught in Binh Thuan Province is small in comparison to the number collected from the more northern provinces. If all four species of lobsters that are collected for aquaculture grow-out are taken into account, the catch area extends from Hon La Gulf (Quang Binh Province) in the north (17.5ºN) to the bays of Binh Thuan Province in the south (11ºN). The light net trap method of catching pueruli evolved from accidental catches of lobster pueruli when using nets to catch schooling anchovy. Active use of the light net catching of lobsters began around 1996. There is speculation that swimming pueruli may use chemical cues for orientation, selection of suitable settlement habitats and possible predator avoidance.

Topic 3: What is the likelihood that spawning cultured lobsters make a positive contribution to future recruits?

No reliable data appear to be available. Information from Vietnamese lobster farmers and buyers is that the berried lobster season is July to September with a peak incidence in August. Hatching of eggs from cultured lobsters has been observed by Xuan Tu lobster farmers. Whether or not such hatching would result in successful pueruli recruiting to the Vietnamese coast 5–6 months later (January–February) is unknown. Additionally, wind and local currents at time of spawning would have to be favourable to enable phyllosoma to be carried out to oceanic water. It is not known if local retention of phyllosoma would enable full development to pueruli (concerns about availability of suitable food types for phyllosoma development and extent of predation on phyllosoma). The extensive spawning migration of *P. ornatus* from the Torres Strait to Yule Island, PNG (500 km) suggests an innate need of the spawners to find a suitable egg release habitat. One suggestion to enhance natural recruitment was to temporarily relocate cultured berried lobsters to a more suitable egg release site. However, identification of such sites would require detailed studies of inshore current patterns/eddies during the spawning season. Lobsters could either be bought from the farmers or returned after spawning.

Topic 4: How reliable are the developed transport models for determining the distribution and origin of lobster phyllosoma?

The Villanoy and Griffin transport models assume phyllosoma have vertical migration capacity but effectively no linear migration other than as influenced by wind movement or current. Tidal effects are thought to be inconsequential during the oceanic phase of phyllosoma development. The pueruli are deemed to swim at or near the surface and to swim towards the closest continental shelf with a life potential to reach a suitable settlement habitat of 30 days (Griffin model). The Villanoy model assumes the larvae have a total life potential of eight months. Reverse modelling of pueruli settlement along the central coast of Vietnam (Villanoy model) shows a large phyllosoma mass originating from southern China waters, with smaller populations potentially from Sabah and northern Philippine waters and locally from the central coast of Vietnam. Spawning *P. ornatus* are unlikely to occur in southern China waters (+21ºN) and this most likely represents some anomaly in the modelling. The Luzon region of northern Philippines would appear to be a more probable spawning origin site. From the strength of current flow in the South China Sea, it is highly improbable for phyllosoma to traverse the whole region (i.e. spawn in southern Vietnam waters and ultimately settle in central coast Vietnam eight months later).

There is insufficient data on the location and abundance of adult *P. ornatus* in Vietnamese waters. The effect of outflow from the Mekong Delta on adult stocks of *P. ornatus* and survival of phyllosoma is unknown. The hypothesis that *P. ornatus* settlement along the central coast of Vietnam is due to self-replenishment needs to be challenged. Similarly, the significance of the up-welling resulting from the convergence of the southerly flowing deep cold current and the northerly flowing surface warm current along the central-southern waters of Vietnam on lobster ecology is not known. Fine-tuning of the Villanoy model using satellite drifter information to give better information on local wind events and surface current patterns may give better estimates of larval transport. Satellite drifter information is a critical element of the Griffin phyllosoma transport model. Effects of El Niño and La Niña events on ocean currents and larval transport are thought to be minor for the Coral Sea but may be more significant influences in the South China Sea.

Some issues that need to be addressed to improve phyllosoma transport modelling are: (i) increase the domain area of the model so that the ultimate fate of the larvae can be tracked better; (ii) information on the nutritional status of phyllosoma in the wild, the type and abundance of food preyed upon by phyllosoma and natural larval development period would enable better estimates of survival/extinction rate; (iii) information on the nature and extent of natural predation that phyllosoma are exposed to during transport is needed to better estimate survival; (iv) the need to ground-truth the larval transport model by either reverse modelling of settlement to identify spawning origin, confirming settlement from known spawning time and site, and/or analysing spatial and temporal plankton trawls to determine the natural regional abundance pattern of phyllosoma; and (v) include data on water movement of different strata in the water column and vertical diel migration of pueruli to improve the model, although it must be recognised that actual migration/movement patterns of the phyllosoma are not reliably known.

Topic 5: Would a genetic population study of *P. ornatus* in the South China Sea assist in determining the origin of settled juveniles?

What is known of the ecology of *P. ornatus* would negate the likelihood of genetically discrete populations occurring in the South China Sea region. Its long oceanic larval development and wide larval transport during this development would imply a genetically well mixed population. However, more sophisticated genetic technologies are being developed, which may enable a better discrimination of sub-populations. Moreover, in the absence of a population genetics study being carried out, there will always be some doubt as to whether or not discrete, self-recruiting populations do exist. This doubt must be removed because management must be done at the level of self-recruiting populations. Part of the problem, of course, is that homogeneous gene frequencies can be maintained between largely self-recruiting populations on the basis of relatively infrequent exchange of propagules. Genetic techniques need to be sensitive enough to be able to infer the rate of exchange, i.e. whether it is rare (essentially self-recruiting) or frequent enough to be confident that if a population is fished down too hard, it could be replenished fairly rapidly from another one. Before initiating a detailed sampling program to determine the genetic structure of South China Sea *P. ornatus*, it would be insightful to first see what genetic differences can be detected in spatially distant populations, e.g. *P. ornatus* lobsters from Indian, Indonesian, Australian, Pacific, Tanzanian and Madagascan waters.

Topic 6: What would be the best management policy to ensure sustainability of lobster seed for aquaculture grow-out and how might such policies be implemented/policed?

Measures used in Australia (release of a proportion (25%) of the original *Jasus edwardsii* seed catch after 12 months aquaculture holding) or New Zealand (trade off of adult quota catch for juvenile collection) were discussed but implementation of such policies in Vietnam and other South China Sea regions was thought to be difficult due to the much looser governance arrangements for coastal fisheries. Likewise, other management practices such as seasonal closures, size limitations, catch quota, gear restrictions, ban on the taking of berried females, are unlikely to be adopted and/or effectively enforced. The prevailing attitude is to fish today (to provide food or generate income) before any collapse occurs. There is considerable competition amongst fishers to catch lobster seed as early as possible so as to increase their catch/income success. However, the Government of Vietnam is working with fishing communities to establish self-managed marine protected areas (MPA) as a conservation measure. Twenty MPA sites have been identified and the first one has been established at Nha Trang. Such MPAs will only be beneficial under a model of self-replenishment, emphasising the critical importance of identifying the location(s) of spawners. The size and location of the MPAs would also be important. Under a scenario of self-replenishment, they would need to be large enough, and located in places where puerulus settle regularly, to protect the number of puerulus needed to replenish the spawning biomass.

The importance of socio-economic studies and community education programs to convince village fishers of the value of conservation and sustainable fishing practices was recognised. This approach is being successfully implemented in the Philippines. Because of the high immediate post-catch mortality of pueruli, Vietnam's Ministry of Fisheries (MoF) is considering a policy to prohibit the taking of lobster seed of less than a certain size (e.g. less than 7 mm carapace length). However, given the expected very high mortality of settling and recently settled puerulus, this is likely to be counter-productive. A better policy would be to encourage the taking of very small seed (where natural mortality is high) but restrict the taking of larger juveniles (e.g. over a carapace size of say, 20 mm). The logic for this is that natural mortality is expected to be inversely related to size and lobsters successfully surviving to, say, 20 mm carapace length would have a good chance of recruiting to the adult population. It would be better to improve handling and transport of the very small pueruli to improve survival and so provide an effective way of increasing the fishery production through aquaculture. There is also a need to consider the recruitment prospects of seed that settle at different locations — Is the central coast of Vietnam a sink or source area for *P. ormatus*? This has key implications for how the settling puerulus are exploited, but does not affect the imperative to identify and protect the spawning biomass producing the larvae. Other important questions prevail. What is the suitability of local habitat for settlement? Does physiological condition of the settling pueruli (energy reserves, etc) vary spatially and temporally? Does this affect natural survival rates and post-capture aquaculture survival.

Topic 7: Is sustainability of the Vietnamese lobster aquaculture industry threatened more by deterioration of the coastal environment than a lack of lobster seed supply?

Lobster farmers, MoF and other authorities are increasingly concerned about the environmental pollution resulting from coastal aquaculture and other eutrophic practices. Lobster farmers at Xuan Tu village experienced severe mortality in caged lobsters in 2001 (up to 50% mortality of large lobsters). Severe bacterial and fungal infections (*Vibrio* spp and *Fusarium* spp, respectively) were isolated from the lobsters but it is not known if they were primary or secondary pathogens. Deteriorating water quality was thought to have precipitated the disease. A similar experience has been seen with intensification of shrimp (*Penaeus monodon*) in the Philippines and other parts of southeast Asia, where fungal, protozoan and bacterial infections preceded more devastating viral diseases such as White Spot Virus. No specific lobster virus has been identified in lobsters cultured in southeast Asia but a very lethal herpes-like virus (HLV-PA) has recently been identified in the Caribbean spiny lobster *Panulirus argus* in the Florida Keys (Behringer et al. 2003).

To counter the disease problem faced by the Xuan Tu lobster farmers, virtually all lobster cages were moved to deeper water (and there is a continuing offshore movement of cages) with many floating cages now evident at the site. There is also anecdotal evidence that lobster productivity has declined over the years, presumably due to deteriorating water quality, but this is confounded by trends over the same period to culture smaller and smaller lobster seed. It now takes typically 18 to 20 months to culture seed lobsters (1-2 g/individual; 8–10 mm carapace length) to a market size of 1 kg.

Why don't lobster farmers all move to deeper water? Not all farmers are convinced that the water quality is so bad and the resultant loss of productivity is so severe to offset the extra cost and logistics of servicing/protecting floating cages. Xuan Tu lobster farmers are adopting mussel and sandfish coculture with lobsters as a means of improving adjacent environmental conditions. Spat of the green mussel (*Perna virdis*) is brought in and cultured for 10–12 months to provide a cheap and 'cleaner' food source for the lobsters. The mussels also presumably play a role in reducing the levels of suspended algae and materials in the water column. Sandfish (*Holothuria scabra*) are held in net enclosures under the lobster cages to feed on the bottom detritus. Some concerns were expressed on the human health implications of microbial or potentially harmful compounds (heavy metal, pesticide, antibiotics, etc) accumulating in mussels, which may then transfer through the food chain. A detailed study on mussel bioaccumulation and transfer/retention to/by lobsters needs to be initiated to verify that this promising form of polyculture will be beneficial.

References

Behringer, D.C., Butler, M.J., Shields, J.D., Ratzlaff, R. 2003. A lethal viral disease infecting juvenile Carribean spiny lobster in Florida Keys. In: Proceedings Florida Keys Lobster Workshop, June 6, 2003. Holiday Inn Beachside, Key West Florida, USA.

Thuy, N.T.B., 1999. Research on biological characteristics of spiny lobsters for protecting their resource. Ph.D thesis. University of Fisheries, Nha Trang, Vietnam. 200 p.

Knowledge gaps and research needs for sustainable management of the South China Sea tropical spiny lobster resource

Problem/issue	Research needs	Methods/approach/strategy
1. Sustainability of seed supply		
How important is collected seed for natural recruitment? • Sink or source population of recruits? • What is the comparative value of seed as stock recruits (physiological condition of seed at settlement; spatial/temporal aspects at settlement; natural predation rate)? • How long can present (increasing) seed collection practices persist before collapse?	1.1 Identify source of settling seed 1.2 Robust data on spatial/ temporal abundance of seed 1.3 Viability of larvae spawned from cultured lobsters 1.4 Physiological condition of settled seed 1.5 Evaluate merits of a small (ca. 20 mm CL) maximum size limit on collection of seed	1.1 Improve, expand and validate larval transport modelling. Assess likelihood of *P. ornatus* population genetic study revealing origin of settled seed (newer molecular genetic tools; global and SCS region analysis). 1.2 Spatial and temporal census of seed collection and CPUE. Fishery independent data on spatial/temporal settlement (monitor spatially-replicated collectors). 1.3 Fine-scale modelling of likelihood of success (spawning time; wind/current movement; inshore vs offshore survival; food source type and availability). Identify suitable habitat for egg release (temporary relocation of berried cultured lobsters). 1.4 Viability of larvae spawned from cultured lobsters. Temporal and spatial sampling of recruits for body composition (and signature lipid) analysis. Sampling of oceanic larvae and plankton for signature lipid analysis. 1.5 Survival of seed of different sizes in the wild (to be done in MPAs to give necessary protection).
2. Source/abundance of spawning *P. ornatus* stock		
Where do the adult *P. ornatus* stocks occur in SCS, What is their abundance and what fishing pressure are they under? • Spatial abundance of stocks • Spawning (seasonality, migration)	2.1 Stock assessment of SCS stock 2.2 Robust data on fishery catch and CPUE	2.1 Annual survey of occurrence, number and size of *P. ornatus* stock. Tag and re-capture to assess behaviour of stocks. 2.2 Implement catch data collection at landing ports and along market chain to identify lobster imports and re-exports
3. Minimising environmental impacts of lobster aquaculture		
Will degradation of the coastal environment resulting from lobster culture and other uses more rapidly impact on sustainability of lobster culture than lobster seed supply? • Vietnam coastal aquaculture will continue to expand • Likelihood of environmental policies being implemented and/or policed?	3.1 Determine environmental impact of present use practices 3.2 Optimal (sustainable) carrying capacity for lobster culture sites 3.3 Improve feed delivery to reduce nutrient discharge	3.1 Desk audit of nutrient flows and pathways: inputs, retention in cultured animal and deposit/discharge from system. Establish environmental benchmarks for comparative monitoring. Examine impacts of other major/potential eutrophication industries; for example, babylon snail at 20,000t p.a., effluents from shrimp farms, etc. 3.2 Gather spatial and temporal data of environmental impacts of use practices (impacts on water quality, microbial type and abundance, sediment fouling). Examine whole system sustainability — benefits/human health concerns of co-culture (lobster/mussel/sandfish) and phytoplankton blooms. 3.3 Develop eco-friendly feeds that reduce reliance on wild fish and invertebrates, reduce feed wastage and increase nutrient retention in cultured animal, including co-culture of mussels, sandfish and other species to provide food and/or ameliorate environment (subject to no implications for accumulation by mussels).

Appendix

Workshop Program

Tuesday 20 July 2004

Session 1: Exploitation of the wild tropical spiny lobster resource of the South China Sea

Chairman: Dr Kevin Williams, CSIRO Marine Research, Cleveland, Australia

10.00–10.30	Arrival and morning tea
10.30–10.40	Welcome and workshop objectives Kevin Williams, CSIRO Marine Research
10.40–11.25	Status of spiny lobster resources of the Philippines Marie Antonette Juinio-Menez and Rachel R Gotanco, Marine Science Institute, University of Philippines, Philippines
11.25–12.10	Status of spiny lobster resources in Sabah waters Rooney Biusing and Chio Fui Lin, Department of Fisheries, Sabah, Malaysia
12.10–1.30	Lunch
1.30–2.15	Current status and exploitation of wild spiny lobsters in Viet Nam waters Nguyen Bich Thuy and Nguyen Bich Ngoc Research Institute for Aquaculture No. 3, Nha Trang, Vietnam
2.15-2.45	General discussion

Tuesday 20 July 2004

Session 2: Lobster aquaculture in the Philippines & Viet Nam

Chairman: Dr Clive Jones, QDPI&F, Cairns, Australia

2.45–3.15	Sustainable farming of spiny lobster in Western Mindanao, Philippines Joseph Arcenal, Provincial Coordinator, R&D Fisheries Division, Zamboanga Del Sur, Philippines
3.15–3.35	Afternoon tea
3.35–4.05	Present status of lobster cage culture in Viet Nam Le Anh Tuan and Nguyen Dinh Mao, University of Fisheries, Nha Trang, Khanh Hoa, Viet Nam
4.05–4.35	General discussion
6.00	Workshop dinner Bao Dai

Wednesday 21 July 2004

Session 3: Lobster ecology and stock assessment

Chairman: Dr Kevin Williams, CSIRO Marine Research, Cleveland, Australia

8.15–9.00	Ecology and stock assessment of the ornate rock lobster *Panulirus ornatus* population in Torres Strait, Australia Darren Dennis, CSIRO Marine Research, Cleveland Queensland
9.00–9.45	Modeling the transport of ornate rock lobster larvae *Panulirus ornatus* in East Australian waters. David Griffin, CSIRO Marine Research, Hobart, Australia
9.45–10.15	General discussion
10.15–10.35	Morning tea
10.35–11.20	Some typical hydrodynamical characteristics of the sea of Viet Nam and adjacent waters Bui Hong Long, Institute of Oceanography, Nha Trang, Khanh Hoa, Vietnam
11.20–12.05	Larval dispersal simulation of the spiny lobster, *Panulirus ornatus*, in the Philippines using merged altimeter-derived absolute dynamic topographies Cesar Villanoy, Marine Science Institute, University of Philippines, Philippines
12.05–12.35	General discussion
12.35–1.45	Lunch

Wednesday 21 July 2004

Session 4: Towards more sustainable South China Sea lobster aquaculture

Chairman: Dr Clive Jones, QDPI&F, Cairns, Australia

1.45–2.15	Mussel and lobster co-culture: A tool for providing live feed and improving environmental quality for lobster aquaculture in Viet Nam Pham Thi Du, Do Huu Hoang, Hoang Trung Du & Vo Thi Hai Thi, Institute of Oceanography, Nha Trang, Khanh Hoa, Viet Nam.
2.15–3.00	Key issues for sustaining aquaculture production of the spiny lobster, *Panulirus ornatus*, in Vietnam Johann D Bell, WorldFish Centre, Penang, Malaysia
3.00–3.30	General discussion
3.30–3.50	Afternoon tea
3.50–4.45	Discussion: Knowledge gaps and research needs to ensure sustainability of South China Sea tropical spiny lobster stocks Leader: Kevin Williams, CSIRO Marine Research, Cleveland, Australia
4.45– 4.50	Workshop close Kevin Williams, CSIRO Marine Research, Cleveland, Australia

Thursday 22 July 2004

Field trip: Inspect lobster cage farming at Xuan Tu village, Khanh Hoa, lobster seed collection at Nha Trang, Research Institute for Aquaculture No. 3, Nha Trang and University of Fisheries, Nha Trang.

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