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Mud crab aquaculture

A practical manual

***Cover photographs*:**
Clockwise from top left: Scylla olivacea – dorsal view, courtesy of Queensland Museum; crablets of S*cylla serrata,* courtesy of Colin Shelley; larval rearing tanks covered with plastic to control aerosol contamination and assist in temperature control, courtesy of David Mann; earthen mud crab pond with netting around the pond, People's Republic of China, courtesy of Chaoshu Zeng; mud crabs packed with head and claws tilted toward the top of the box, courtesy of Colin Shelley.

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Colin Shelley
FAO Consultant
Australia

and

Alessandro Lovatelli
Aquaculture Officer
Aquaculture Service
FAO Fisheries and Aquaculture Department
Rome, Italy

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Preparation of this document

While mud crab farming based on collection of crablets or crabs from the wild for fattening or grow-out has probably taken place for hundreds of years, hatchery production of mud crabs is a relatively recent innovation, with most research and development taking place over the last few decades.

This manual attempts to showcase the current wisdom on mud crab farming from key nations in the Asia-Pacific region where research and development, significant industry development and extension of technology have occurred in recent years.

The development of this manual reflects contributions from all major organizations and research teams involved in mud crab culture development. Attendance at numerous workshops and conferences on crab fisheries and aquaculture over the past couple of decades has provided inspiration and insight into the need for a manual such as this, one that brings together the whole process of mud crab farming from broodstock to high-quality product leaving the farm.

This manual has benefited from so many farmers, scientists, fisheries professionals, business owners, information specialists and technicians who have been kind enough to share their knowledge and skills, that to name a few might devalue the contribution of others – so to you all, thank you.

The support, patience and enthusiasm of Alessandro Lovatelli, FAO Aquaculture Officer, was critical to the completion of this publication.

Abstract

There are four species of mud crab, *Scylla serrata*, *S. tranquebarica*, *S. paramamosain* and *S. olivacea* that are the focus of both commercial fisheries and aquaculture production throughout their distribution. They are among the most valuable crab species in the world, with the bulk of their commercial production sent live to market. This is the first FAO aquaculture manual on this genus, covering everything from its basic biology and aquaculture production, through to stock packaging and being ready to go to market.

Information on mud crab biology, hatchery and nursery technology, grow-out systems, disease control, processing and packaging has been collated in this manual to provide a holistic approach to mud crab aquaculture production. Compared with other types of aquaculture, mud crab culture still has a large number of variants, including: the use of seedstock collected from the wild, as well as produced from a hatchery; farming systems that range from very extensive to intensive, monoculture to polyculture; and farm sites that vary from mangrove forests to well-constructed aquaculture ponds or fattening cages. As such, there is no one way to farm mud crabs, but techniques, technologies and principles have been developed that can be adapted to meet the specific needs of farmers and governments wishing to develop mud crab aquaculture businesses.

Each of the four species of *Scylla* has subtly different biology, which equates to variations in optimal aquaculture production techniques. Where known and documented, variants have been identified, where not, farmers, researchers and extension officers alike may have to adapt results from other species to their mud crab species of choice and local climatic variables. Compared with many other species that are the subject of industrial scale aquaculture, mud crabs can still be considered to be at an early stage of development, as the use of formulated feeds for them is still in its infancy and little work has yet been undertaken to improve stock performance through breeding programmes.

Shelley, C.; Lovatelli, A.
Mud crab aquaculture – A practical manual.
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Abbreviations, acronyms and conversions

BCD	bitter crab disease
Code	Code of Conduct for Responsible Fisheries
CUC	commercially unsuitable crab
CW	carapace width
DAC	Darwin Aquaculture Centre (Australia)
DHA	docosahexaenoic acid
DNA	deoxyribonucleic acid
EPA	eicosapentaenoic acid
FCR	feed conversion ratio
HACCP	Hazard Analysis and Critical Control Point (system)
HAT	highest astronomical tide
HUFA	highly unsaturated fatty acid
IFAT	Indirect Fluorescent Antibody Technique
LWS	low water of spring tides
MCRV	mud crab reovirus
OTC	oxytetracycline
PCD	pink crab disease
PCR	polymerase chain reaction
RNA	ribonucleic acid
rRNA	ribosomal RNA
SEAFDEC	Southeast Asian Fisheries Development Center
TAN	total ammonia nitrogen
TSV	Taura syndrome virus
UV	ultraviolet
WIO	Western Indian Ocean
WSSV	white spot syndrome virus

Not all of the following abbreviations have been used in this manual. However, they are provided as reference when reading other documents.

<	less than
>	greater than
n.a.	not analyzed or not available (also written as N/A)
µm	micron
mm	millimetre
cm	centimetre
m	metre
km	kilometre
inch	inch
ft	foot
yd	yard
mi	mile
ft^2	square foot
yd^2	square yard
mi^2	square mile

m^2	square metre
ha	hectare
km^2	square kilometre
cc	cubic centimetre (= ml)
m^3	cubic metre
ft^3	cubic foot
yd^3	cubic yard
µl	microlitre
ml	millilitre (= cc)
l	litre
µg	microgram
mg	milligram (milligramme)
g	gram (gramme)
kg	kilogram (kilogramme)
mt	metric tonne (1 000 kg) (also written as tonne)
oz	ounce
lb	pound
cwt	hundredweight [value differs in UK ('Imperial') and US units - see weight conversions]
t	ton [value differs in UK ('Imperial') and US units - see weight conversions]
psi	pounds per square inch
psu	practical salinity units
gpm	('Imperial' = UK) gallons per minute
mgd	million ('Imperial' = UK) gallons per day
cfm	cubic feet per minute
ppt	parts per thousand (also written as ‰)
ppm	parts per million
ppb	parts per billion (thousand million)
min	minute
hr	hour
kWhr	kilowatt-hour

CONVERSIONS

Please note that the words gallon and tonne have different values depending on whether the source of the text you are reading is 'British' or 'American' in origin.

Length:

1 µm	0.001 mm = 0.000001 m
1 mm	0.001 m = 1 000 µm = 0.0394 inch
1 cm	0.01 m = 10 mm = 0.394 inch
1 m	1 000 000 µm = 1 000 mm = 100 cm = 0.001 km = 39.4 inch = 3.28 ft = 1.093 yd
1 km	1 000 m = 1 093 yd= 0.621 mi
1 inch	25.38 mm = 2.54 cm
1 ft	12 inch = 0.305 m
1 yd	3 ft = 0.914 m
1 mi	1 760 yd = 1.609 km

Weight:

1 µg	0.001 mg = 0.000001 g
1 mg	0.001 g = 1 000 µg
1 g	1 000 000 µg = 1 000 mg = 0.001 kg = 0.0353 oz
1 kg	1 000 g = 2.205 lb
1 mt (or tonne)	1 000 kg = 1 000 000 g = 0.9842 UK t = 1.102 US t
1 oz	28.349 g
1 lb	16 oz = 453.59 g
1 UK cwt	112 lb = 50.80 kg
1 US cwt	100 lb = 45.36 kg
1 UK t	20 UK cwt = 2 240 lb
1 US t	20 US cwt = 2 000 lb
1 UK t	1.016 mt = 1.12 US t

Volume:

1 µl	0.001 ml = 0.000001 litre
1 ml	0.001 litre = 1 000 µl = 1 cc
1 litre	1 000 000 µl = 1 000 ml = 0.220 UK gallon = 0.264 US gallon
1 m^3	1 000 litres = 35.315 ft^3 = 1.308 yd^3 = 219.97 UK gallons = 264.16 US gallons
1 ft^3	0.02832 m^3 = 6.229 UK gallons = 28.316 litres
1 UK gallon	4.546 litres = 1.2009 US gallons
1 US gallon	3.785 litres = 0.833 UK gallon
1 mgd	694.44 gpm = 3.157 m^3/min = 3 157 litres/min

Concentration – dissolving solids in liquids:

1 %	1 g in 100 ml
1 ppt	1 g in 1 000 ml = 1 g in 1 litre = 1 g/litre = 0.1%
1 ppm	1 g in 1 000 000 ml = 1 g in 1 000 litres = 1 mg/litre = 1 µg/g
1 ppb	1 g in 1 000 000 000 ml = 1 g in 1 000 000 litres = 0.001 ppm = 0.001 mg/litre

Concentration – dilution of liquids in liquids:

1 %	1 ml in 100 ml
1 ppt	1 ml in 1 000 ml = 1 ml in 1 l = 1 ml/l = 0.1%
1 ppm	1 ml in 1 000 000 ml = 1 ml in 1 000 l = 1 µl/l
1 ppb	1 ml in 1 000 000 000 ml = 1 ml in 1 000 000 l = 0.001 ppm = 0.001 ml/l

Area:

1 m^2	10.764 ft^2 = 1.196 yd^2
1 ha	10 000 m^2 = 100 ares = 2.471 acres
1 km^2	100 ha = 0.386 mi^2
1 ft^2	0.0929 m^2
1 yd^2	9 ft^2 = 0.836 m^2
1 acre	4 840 yd^2 = 0.405 ha
1 mi^2	640 acres = 2.59 km^2

Temperature:

°F	(9 ÷ 5 × °C) + 32
°C	(°F – 32) × 5 ÷ 9

Pressure:

1 psi	70.307 g/cm^2

SCIENTIFIC UNITS

Scientists have a different way of writing some of the units described in this glossary. They use what is called the Système International (SI). The units are referred to as SI units. For example: 1 ppt, which can be written as 1 g/litre (see concentration above) is written as 1 g $litre^{-1}$ in scientific journals; 1 g/kg is written as 1 g kg^{-1}; 12 mg/kg would be written as 12 mg kg^{-1}; 95 µg/kg would be written as 95 µg kg^{-1}. A stocking density of 11 kg/m^3 would be written as 11 kg m^{-3}. More information about this topic can be found on the Internet by searching for SI units.

Glossary

Antennae	Pair of thin sensory appendages found on the head of crustaceans.
Autotomy	The spontaneous casting off a limb or other body part by an animal when injured or to facilitate escape when under attack.
Berried	Or bearing eggs. In larger crustaceans (e.g. lobsters, crabs), a term, which is used to describe those females with large egg masses attached under the abdomen during the period of incubation.
Biosecurity	Procedures to protect animals or humans against disease or harmful biological agents.
Brackish water	Water with a salinity intermediate between seawater and freshwater, usually showing wide salinity fluctuations. Brackish water is commonly found in estuaries.
Broodstock	Mud crabs of both sexes maintained for controlled breeding purposes.
Burrowing	Making a hole or tunnel.
Cannibalism	Intraspecific predation. Eating flesh of its own species.
Carapace	The protective shell of crabs also known as exoskeleton.
Cellular systems	Culture systems constructed of individual cells.
Chela	The pincer-like claw of a crab or other crustacean.
Conditioning	Train or condition something to behave in a particular way or to improve its condition, e.g. nutrition.
Copulation	Or mating. Pairing animals for breeding purposes.
Crablets	Juvenile, post-larval mud crabs that have yet to obtain sexual maturity, subadults.
Dactyl	The claw or terminal joint of a leg of a crustacean.
Empty crab	A crab that has recently moulted (see moult), with high water content and low meat yield.
Fattening	Intensive feeding to raise the farmed animal to market size.
Feed conversion ratio (FCR)	The ratio of the gain in the wet body weight of the animal to the amount of feed fed.

Fungus	Any of a group of primitive saprophytic and parasitic spore-producing eukaryotic typically filamentous plants that lack chlorophyll and include molds, rusts, mildews, smuts, mushrooms and yeasts.
Haemolymph	The invertebrate equivalent of blood in the circulatory system.
Hatchery	A system and/or building where mud crabs are reared through their larval stages.
Hatching	The breaking of eggs and release of larvae.
Incubation	The process of incubating eggs, i.e. the period during which embryos develop inside the eggs. In mud crabs the eggs are incubated between spawning as a large egg mass, also known as "sponge", attached under the abdomen of females.
Intertidal	The area between high and low tides; also known as the foreshore and seashore and sometimes referred to as the littoral zone.
Intermoult	The period between the moulting of crabs or description of a stage of the moult cycle.
Larvae	Or the plantonic immature phase of mud crabs. An organism from the beginning of exogenous feeding to metamorphosis into juvenile. At the larval stage the animal differs greatly in appearance and behaviour from a juvenile or an adult.
Maggots	A non-technical term to describe the larvae of flies.
Mangroves	A tidal salt marsh (intertidal) community dominated by trees and shrubs, particularly of the genus Rhizophora, many of which produce adventitious aerial roots. Develops in tropical and subtropical areas, in predominantly muddy or sandy substrates, and along protected coastlines.
Megalopa	The final larval stage of mud crabs, prior to their settlement to the benthic phase of their life cycle.
Metamorphosis	The process of changing shape or structure in the transition of one developmental stage into another or from an immature form to a mature form in two or more stages.
Microalgae	Microscopic algae typically found in fresh and marine waters.
Monoculture	A single species grown on its own.
Moult	Common name for the exuvium, i.e. the shed of the old exoskeleton to make way for a new layer. To moult: process of shedding the exoskeleton.

Nursery	A system or facility where post-larval mud crabs or crablets are reared to a size suitable for stocking in grow-out pond or other rearing units.
Ovary	The female reproductive organ of mud crabs.
Ozone treatment	Ozone used as an oxidizing agent to sterilize water.
Pathogens	A bacterium, virus or other microscopic organism that can cause disease in its animal or plant host.
Pens	Simple structures to contain mud crab stock for grow-out.
Phototactic	Demonstrates a positive movement toward light.
Polyculture	The rearing of two or more non-competitive species in the same culture unit.
Prophylaxis	Action taken to prevent disease by specific means or against a specific disease.
Quarantine	A state, place or period of isolation in which animals have arrived from elsewhere as they may have been exposed to disease.
Salinity	An expression for the concentration of soluble mineral salts and chlorides in water; usually expressed as parts per thousand (ppt).
Scylla	The scientific genus that mud crab species belong to.
Silviculture	The growing and cultivation of trees.
Spawning migration	A migration of female crabs from their usual habitat to another habitat for the purpose of spawning and hatching their eggs.
Sponge	The egg mass of female crabs held externally under their abdomens.
Subtidal	The shallow marine or tidal flat environment that is below the mean low water level of spring tides.
UV (Ultraviolet sterilization)	Ultraviolet radiation utilized to sterilize water.
Water crab or water bag	A crab that has recently moulted and typically has a high water content but low meat yield.
Zoea	The early larval stage of mud crabs.
Zooplankton	Plankton consisting of small animals and the immature stages of larger animals.

Part 1

Biology

1.1 TAXONOMY AND GENETICS

The taxonomy of the mud crabs has been clarified using allozyme electrophoresis, DNA sequencing and morphometrics to identify four *Scylla* species from crabs collected throughout their distribution from the Red Sea to the Indo-Pacific. The species are *S. serrata* (Forskal, 1775), *S. olivacea* (Herbst, 1796), *S. tranquebarica* (Fabricius, 1798), and *S. paramamosain* (Estampador, 1949). That study has been followed up by other work using sequential analysis of mitochondrial 12S rRNA from mud crabs from Japan, Madagascar and Thailand, and further DNA and RNA analysis that demonstrated that larval, as well as juvenile mud crabs could be confidently described using the revised taxonomic nomenclature.

As a result of the recent taxonomic clarification of *Scylla*, results from earlier studies should be assessed with care as the species quoted may no longer be accurate and, in some cases, investigations may have been undertaken on a number of species of *Scylla*, but were assumed to have been a study of just one species.

Other contemporary studies on the genetics of *Scylla* were either not able to separate all four species satisfactorily or only examined limited species from the genus.

In Viet Nam, electrophoresis and morphometrics have been utilized to identify the key commercial species in the Mekong Delta as *S. olivacea* ("red crab") and *S. paramamosain* ("green crab"), based on the recent revision of the genus.

An improved understanding and reporting of the mud crab genotype has led to better understanding of their population structure. For example, while Madagascan and South African populations of *S. serrata* could be separated, populations of mud crabs from six South African estuaries were reportedly homogeneous. Similarly, in Australia, a mitochondrial coding gene for *S. serrata* was used to identify regional haplotype differences in populations, one of which was related to the natural physical barrier of the Torres Strait. Microsatellite markers are now available for mud crabs and can be used to characterize populations of both *S. serrata* and *S. paramamosain*, and assist in parentage determination. Microsatellite markers were used to assess the genetic diversity of *S. serrata* populations from five Micronesian islands, finding that no significant difference could be found between them, even though they were geographically widely distributed.

In China, six populations of *S. serrata* were able to be separated based on discriminant morphometric analysis, with one of the six populations being significantly different from the other five. However, the most common species of mud crab in China and Viet Nam is *S. paramamosain*, which was ascertained by analysis of their mitochondrial 16S rRNA and confirmed by similar analysis using mitochondrial 12S rRNA.

An improved understanding of the genetics of mud crabs has enabled the success of stock enhancement work to be more accurately gauged. It has also provided a firm foundation for the conservation of wild mud crabs and is of great value for the future breeding programmes of domesticated stock.

Figures 1.1–1.4 illustrate the four species of *Scylla* and details of their claws.

FIGURE 1.1
Scylla serrata **– dorsal view (top) and claws (bottom)**

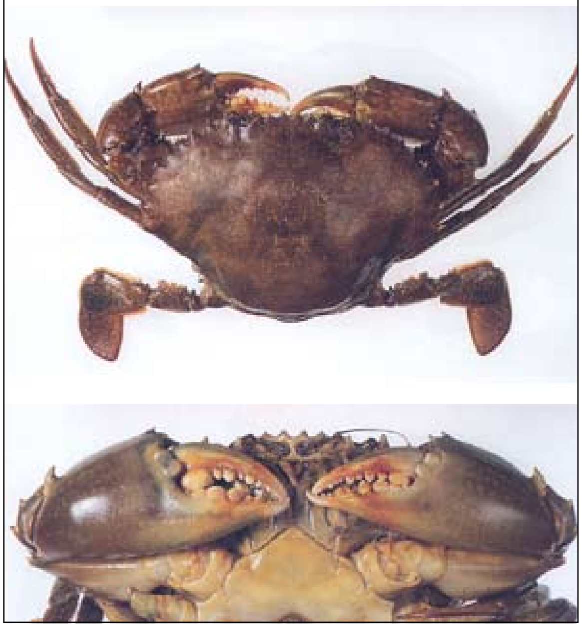
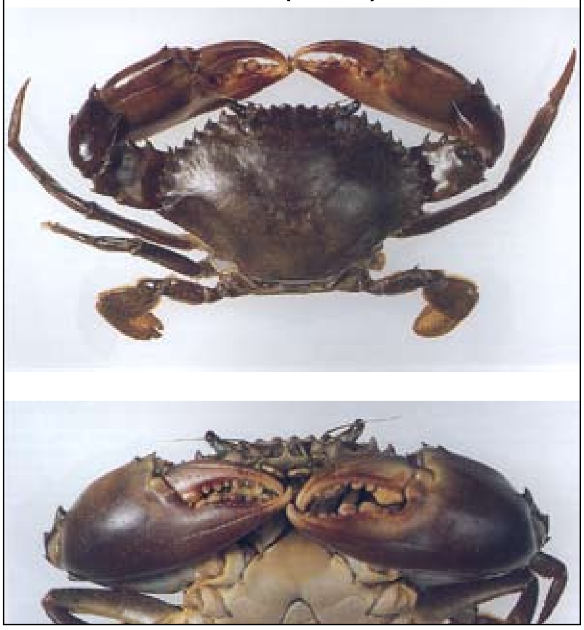


FIGURE 1.2
Scylla paramamosain **– dorsal view (top) and claws (bottom)**

COURTESY OF QUEENSLAND MUSEUM

FIGURE 1.3
Scylla olivacea **– dorsal view (top) and claws (bottom)**

FIGURE 1.4
Scylla tranquebarica **– dorsal view (top) and claws (bottom)**



COURTESY OF QUEENSLAND MUSEUM

Figures 1.1–1.4 reproduced with permission from Keenan, Davie and Mann (1998).

1.2 DISTRIBUTION

1.2.1 Local distribution

Within local populations of mud crabs, their distribution is characterized by significant ontogenic changes, with some studies reporting juveniles more common in seagrass and algal beds associated with mangroves. In an Australian bay, *S. serrata* juveniles of different sizes, subadults and adults were all found to favour different zones from the upper intertidal through the mangrove forest, intertidal and subtidal. A sandstone shelf at the mouth of the Caboolture River, Queensland, Australia, associated with a mangrove system was found to be a good location to collect juvenile *S. serrata*. The juvenile crabs typically sheltered under loose slabs of sandstone and other rocks, or within clumps of mangrove roots, shaded by mangrove trees (*Avicennia marina* and *Ceriops tagal*) between mean high water and mean spring low water. In Micronesia, deep soils alongside a river, branches, logs and hollow mangrove trunks (*Sonneratia alba*) provided the best habitat for *S. serrata* as determined by burrow density. Significantly larger *S. serrata* were found in fringe channels near the edge of the mangrove forest, compared with the interior of the forest. Chemical tracers have been used to show that while some adult populations of *S. serrata* feed predominantly within mangroves, others forage more on reef flats and seagrass beds.

Examination of crab zonation patterns from mangrove forests in Australia, Indonesia and Japan have shown that *Scylla* spp. dominate the zone below mean low water of spring tides (LWS) in all three locations, with their mode of life of the genus being classified as "decapods always living in a burrow".

Apart from spawning migrations, mud crabs appear to move little within their habitat, most remaining on site in distinct populations. However, longer-term tagging has shown that crabs can move several kilometres from their home range over time. Nightly movements of *S. serrata* fitted with transmitters averaged 461 m, with average speeds in the range of 10–19 m/h.

Distinct differences have been reported for the habitat preferences of *S. paramamosain* of different sizes. Small crablets (carapace width [CW] 0.5 cm) settle on the outer edge of mangroves, gradually moving deeper into the forests living on the surface of mangroves (CW 1.5 cm), while larger crabs dig burrows or live in the subtidal zone migrating in to feed in the mangroves at high tide (CW 4.5 cm), with the main adult crab population living subtidally, offshore (CW 12.5 cm). The boundary between the mangroves and mud crab flats is identified as an area that can support higher densities of crabs.

While several species of mud crab can be present in any one location, it appears common that one species makes up a dominant percentage of the overall crab population, for example in Aklan, the Philippines, *S. olivacea* comprised 95 percent of the mud crab population, with 2 other species present in the same area.

As mud crabs appear to have an interdependent relationship with mangrove forests, the loss of mangroves, for whatever reason, will typically be followed by lower crab catches. However, mud crabs are found in estuaries without mangroves, so they are not essential for their colonization or survival.

1.2.2 Global distribution patterns

Analysis of the genetic population of *S. serrata* revealed that there are three distinct genetic stocks located in the Western Indian Ocean (WIO); eastern Australia and the Pacific Ocean; and northwestern Australia. The most widely distributed species of mud crab, *S. serrata*, is found as far west as South Africa, east to Tahiti, French Polynesia, as far north as Okinawa, Japan, and south to Sydney, Australia. The distribution of *S. tranquebarica* and *S. olivacea* is limited to the South China Sea, extending into both the Indian Ocean and western Pacific, while *S. paramamosain* is the most restricted species found only in the Java and South China Seas (Table 1.1).

In the Pacific, it can be assumed that any tropical island that has mangrove forests and a fluvial delta is likely to support a population of mud crabs.

The widespread distribution of *Scylla* spp. is assisted by a planktonic larval stage of several weeks duration that supports good gene flow between nearby populations. At a regional level, the genetic structure of *S. serrata* has been linked to hydrological circulation, supporting the theory that mud crab spawning migrations away from the coast assist gene dispersal, particularly along areas of coastal shelf. It has also been

TABLE 1.1
Distribution and habitat of *Scylla* species

Species	Distribution	Habitat
S. serrata	Indian Ocean, Red Sea, Pacific Ocean – the most widespread *Scylla* species.	Associated with mangrove forests inundated with full salinity oceanic water for the greater part of the year. Can tolerate reduced salinity.
S. paramamosain	South China Sea, Java Sea – an abundant species where it occurs.	Associated with various habitats including shallow coral rubble; shallow subtidal flats and estuarine ponds; mangrove forests.
S. olivacea	South China Sea, Indian Ocean, Pacific Ocean – moderately widespread, often associated with *S. tranquebarica.*	Associated with mangrove forests and coastlines inundated with reduced salinity seawater during the wet season.
S. tranquebarica	South China Sea, Pacific Ocean, Indian Ocean – a widespread species, often associated with *S. olivacea.*	Associated with mangrove forests and coastlines inundated with reduced salinity seawater for part of year.

Source: Keenan, Davie and Mann, 1998.

hypothesized that recruitment events enhanced by unusual current conditions have led to new populations of *S. serrata* being established outside of their recent distribution in southwest Australia, further demonstrating the species' successful distribution strategy.

1.3 LIFE HISTORY

While mud crab megalopae appear not to be selective among estuarine habitats (seagrass, mud or sand), crablets (juvenile mud crabs) strongly select for a seagrass habitat, indicating that living within seagrass beds likely increases their survival. This supports the theory that mud crabs settle out of the plankton in the nearshore region of the coastal shelf and it is the crablets that colonize the estuaries. Crablets have also been reported to shelter in a variety of inshore habitats including reed beds, areas of aquatic macrophytes, under stones and within the mud and sandy sediments.

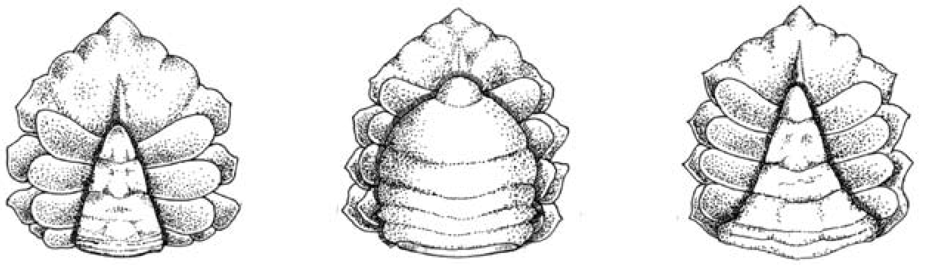
An interesting aspect of the maturation of mud crabs is their apparently step-wise maturation process, where they pass through an apparent physiological maturation, before becoming functionally mature. In *S. serrata*, the first stage of maturation for a male occurs from CW 90–110 mm, while from CW 140–160 mm males develop their characteristic "large-claw" and mating scars on their sternum and front walking legs become apparent. A sudden change in the chela height to CW ratio has also been linked to functional maturation of males in *S. paramamosain*. The absence of mating scars does not confirm that a male is immature, as these can be lost between moults.

In immature *Scylla* spp., a chitinous protrusion from the sternite engages the abdomen, preventing it from opening, so that abdominal disengagement is required before either males or females can mate. In female mud crabs, the characteristic U shape of their abdominal flap, together with a well-developed fringe of setae around it, is a more obvious sign of maturation, together with their heavily pigmented abdomen and highly setose pleopods. Copulation typically follows the change of the abdomen from the more triangular immature female to the more rounded, broad form (Figure 1.5).

Typically, males guard mature females, cradling them prior to their moult (Figure 1.6). The male carries the female underneath him using three pairs of walking legs. The male can successfully mate and transfer spermatophores (packets of sperm) into the female's spermathecum once she has moulted and is soft shelled. During copulation, which may last 7–18 hours, the male turns the female upside down (Figure 1.7). The female stays in the protection of the male until her shell is fully hardened, which may be several days.

The subsequent development of the ovary can be seen by depressing and pushing forwards the first abdominal segment next to the carapace on female crabs. Ovaries change colour as they mature, progressing from transparent through to yellow and finally dark orange, although a more accurate description of the maturation process can be obtained through microscopic examination.

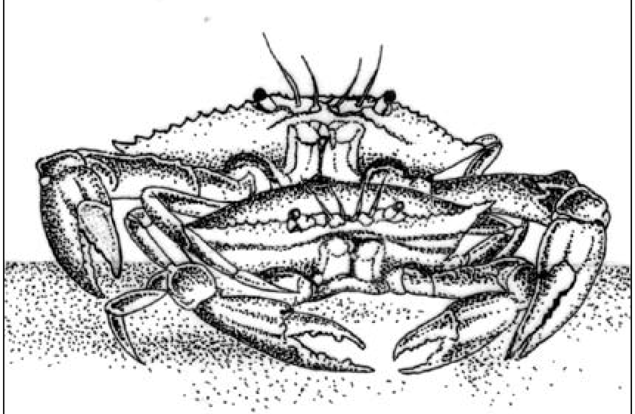
FIGURE 1.5
Abdomens of immature, mature female and mature male *Scylla serrata*



Source: Reprinted with permission of SEAFDEC.

A mature female mud crab produces from 1 to 6 million eggs, with the larger species producing larger numbers of eggs, and larger individuals typically carrying more eggs. Females retain sperm after mating so that 2 or even 3 egg masses can be produced without the further intervention of a male. As males can sense when mature females are ready to moult and so be receptive to mating, it is estimated that over 95 percent of all hard-shelled mature females have been mated and will become ovigerous.

FIGURE 1.6
Male cradling female *Scylla serrata*



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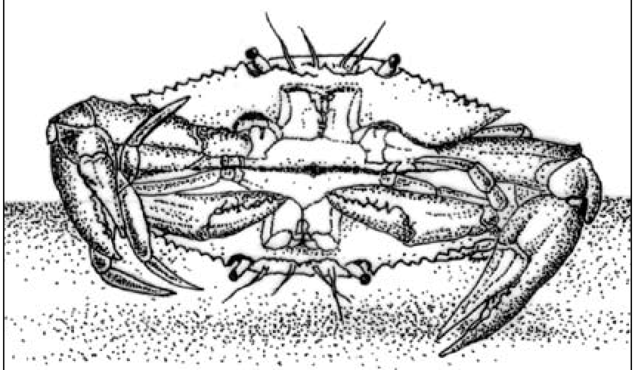
Once eggs have been spawned and an egg mass (or sponge) produced (Figure 1.8), the time to hatching and the release of larvae is temperature dependent, with a shorter time to release at higher temperatures within the animals natural temperature range, and longer times at lower temperatures. Once released, the longevity of each larval stage is similarly temperature dependent, with survival rates linked to both temperature and salinity. As a result, the length of time of the five zoeal stages and the one megalopa larval stage found in the plankton can vary considerably before settlement to the first crablet stage (C1). In the tropical and subtropical parts of their distribution, recruitment can occur throughout the year, while towards the temperature limits of their distribution it is more seasonal, linked to water temperature.

FIGURE 1.7
Mating of *Scylla serrata* with male uppermost and female turned upside down



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As the crablets grow (Figure 1.9), they can moult up to 15 times in the case of *S. serrata* to reach their legal size of 150 mm in Australia; however, two further moults may still occur prior to death. The differential shape of the male and female abdomen can be used to determine the sex of *S. serrata* over 3 cm CW. This species is found up to 24 cm CW in Australia; however, most reach 15 to 20 cm CW. As the crabs grow, the intermoult period gradually increases; however, during the coolest months, toward the southern extremities of their distribution, mud crabs appear to stop moulting until the temperature increases.

FIGURE 1.8
An egg mass (or sponge) of *Scylla serrata*; black colour indicates hatching is imminent

COURTESY OF DAVID MANN

FIGURE 1.9
Crablets of *Scylla serrata*

COURTESY OF COLIN SHELLEY

1.4 BEHAVIOUR

1.4.1 Cannibalism

Cannibalism among mud crabs is a behavioural trait that as yet is poorly understood, but currently presents a major problem for culturing them in open systems at anything other than low density. Investigations into the influence of moulting and injured animals on juvenile mud crab behaviour has failed to find significant links, even though crabs of different size and sex exhibited different responses to stimuli. This work also hypothesized that if cannibalistic behaviour had a genetic basis, then major advancements could be made through selection for traits more suitable to high-density culture. By holding mud crabs in individual containers, as in fattening operations, survival can be dramatically improved compared with pond-reared crabs where cannibalism is prevalent.

Work on another species of crab, *Callinectes sapidus,* identified that, where and when a crab moults may significantly affect its survival, with more complex microhabitats supporting higher survival.

1.4.2 Migration and movement

The spawning migration of female mud crabs from the mangrove forests to offshore habitats has been well documented and seems to be a behaviour shared by all *Scylla* spp. The spawning migrations of female *S. serrata* into deep water (10–60 m) and often kilometres offshore is argued to provide an effective dispersal mechanism, allowing potential recruitment to areas distant from that occupied by the breeding stock.

In Micronesia (Federated States of), spawning migrations of *S. serrata* appear to take place with a lunar periodicity, with female crabs moving from the mangrove forests across reef flats and presumably into deeper water over the last quarter of the moon until three days after the new moon.

Following the spawning migration, about a month later, a migration of young crabs towards brackish water has been reported in the Philippines, with vast numbers being found in river mouths and along the shoreline. Swarms of young crabs are sometimes left exposed on the mud during an ebb tide.

Mud crabs also move from mangrove forests to nearby reef flats and seagrass beds to feed on a routine basis.

Mud crabs are more active nocturnally. This, combined with their habit of routinely burying or burrowing in sediments and regular exposure to air, minimizes the build up of epibionts on the outer layer of their carapace. The burrowing habit of mud crabs has also been reported to negatively affect pond or embankment structures; however, personal observations suggest that this is not a major problem in most mud crab farming operations and that there are species with specific differences in burrowing behaviour, with *S. serrata* having the least impact on earthen structures.

1.5 ECOLOGY

The preferred habitat of mud crabs is mangrove forests or swamps, typically associated with sheltered tropical to subtropical estuaries and embayments. Mangrove vegetation is important to mud crabs as it provides both habitat and food supply.

Mud crabs, like most intertidal organisms, respond to key factors in their environment such as temperature and salinity, constantly modifying their metabolic functions such as respiration and excretion in efforts to maintain homeostasis. Their moult cycle is another important driver of internal metabolic processes.

The salinity tolerance of mud crabs enables them to survive in freshwater for a few hours and hypersaline conditions for extended periods, while their ability to breathe air enables them to utilize their habitat effectively even at low tide and leave water that has a low oxygen level.

Mud crabs can be found in a variety of microhabitats around mangrove forests. However, burrows into the mud, commonly at approximately 30° to the horizontal are often used as refuges for subadult and adult crabs.

Reported densities of mud crabs per hectare of mangrove area vary from lows of 4–80 through to over 1 000. However, the lower numbers reported appear to have been based only on the collection of large crabs from size-selective traps that provided biased samples, whereas other higher estimates of total densities have included multiple collecting methods and have sampled crabs of all sizes. In addition, if pots used to sample mud crabs are not cleared regularly, a population of large crabs can be significantly underestimated, with catches from regularly cleared traps (every 2 hours) producing up to 400 percent higher catches than traps cleared once a day.

1.5.1 Feeding

Mud crab diet in the wild consists mainly of marine detritus, molluscs, crustaceans and fish, the importance of which to their diet appears to vary with location. In Pohnpei, Micronesia (Federated States of), the mangrove clam, *Geolina papua*, was found in 39 percent of *S. serrata* guts examined. Mud crabs are capable of catching live fish and shrimps, seizing them with their chelae.

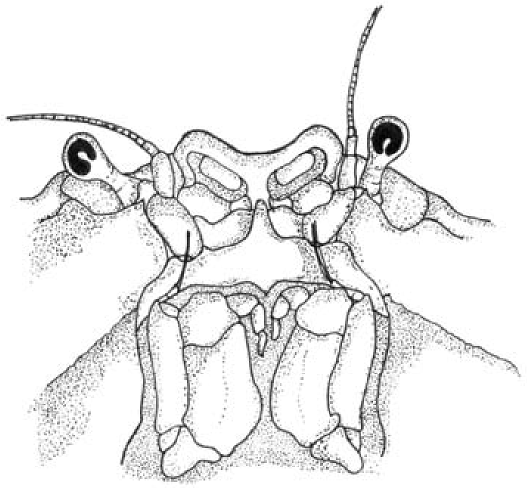
The potential importance of plant-based nutrient sources to mud crabs has been recognized by work that found their high apparent digestibility coefficient for cellulose, soybean and rice bran in formulated diets, together with their ability to readily consume starches, indicating that the marine detritus component of their diets in the wild may be more important than had been previously considered. Although one of the earliest descriptions of mud crab life history described them feeding on algae, decaying wood and bamboo sticks, mud crabs can probably best be described as omnivores, which scavenge throughout their local range for a wide range of food sources, although their cannibalistic tendencies are also well documented. There appears to be little difference in their natural food preferences from juvenile, through subadult to adult (Table 1.2).

TABLE 1.2
Percentage composition of natural food of *Scylla serrata* of different ontogenetic stages, Indonesia

	Juveniles	Subadults	Adults
Food item			
Unidentified organic matter – meat	42.09	46.30	41.09
Inorganic sand-shell	9.46	15.04	17.18
Plant, algae & sea grasses	13.05	12.88	16.00
Fish meat & hard parts	17.41	12.18	10.24
Mollusc	9.21	7.18	8.58
Crustacea	8.20	5.16	4.56
Unidentified organic matter – wood	0.57	1.26	2.24

Source: La Sara *et al*., 2007.

FIGURE 1.10
Eyes and mouthparts of *Scylla serrata*



Source: Reprinted with permission of SEAFDEC.

The amount of nutrition derived from mangrove forests varies from site to site, with some mud crabs gaining a greater percentage of their nutrition from nearby reef flat areas or seagrass beds than others.

As feeding rates are temperature dependent, lower feeding rates can be expected in the cooler months and may in part explain longer intermoult periods observed during winter months in the more temperate extent of mud crab distribution, where nutrient reserves may become limiting.

1.6 ANATOMY

"*The eyes are on stalks, but they can be folded back neatly into the protecting eye sockets. The two pairs of antennae between the eyes detect minute changes in water currents and water chemistry, and just below the antennae there are two small openings through which urine is excreted…*" (Figure 1.10).

"The mouth of the mud crab is covered by six layers of paired appendages. The outer five pairs may be used directly to locate, catch and manipulate small food organisms such as those encrusting mangrove roots. Larger food organisms, many of which live below the surface of mangrove mud, are detected and retrieved by probing movements of the walking legs. The tips (dactyls) of the walking legs, like the outer mouthparts, are highly sensitive to touch and taste. With its large and powerful claws, the mud crab is particularly well adapted to consume large food organisms encased in hard protective shells such as molluscs (oysters, mussels, pippies, winkles, etc.) and hermit crabs, which abound in mangrove estuaries…

Once the shells of larger food organisms have been crushed by the claws, they are passed to the outer mouthparts where hard indigestible fragments are sorted and discarded. The remaining soft choice tissues are then passed to the inner (sixth) pair of stout jaws (mandibles) where pieces are bitten off and swallowed…

Underneath the triangular abdominal flap in the male there are a pair of large tubular pleopods, each with a smaller one inserted into its base like a plunger. These are used to transfer sperm into the females during mating. The mature female has a much broader abdomen, which covers the paired female openings and carries four pairs of forked pleopods with thick hairy edges to which the eggs are attached when laid…"

Quote from: Fielder and Heasman, 1978.

Mud crabs have claws (chelae) with different functions; the right-hand is a "crusher" and the left-hand a "cutter". There is a significant difference in the development of male and female claws such that the weight of a large mature male's "crusher" is approximately 2.5 times that of a female claw from a crab of the same size for *S. serrata*. The contribution of the claws to the total body weight of male mud crabs increases with ontogenetic phase (Table 1.3). However, up until a CW of approximately 10 cm, the gross morphology of male and females are essentially the same. Differences in weight between male and female *S. serrata* are most apparent in large crabs with males of 15 cm CW and 20 cm CW weighing 55 percent and 80 percent, respectively, more than females of the same CWs.

TABLE 1.3
The percentage contribution of claws to total body weight of male and female *Scylla serrata* at different ontogenetic phases

Total weight of crab (g)	% weight contributed by claws – male	% weight contributed by claws – female
1.0	21	21
165	26	–
668	40	22
2 193	50	20

Source: Heasman, 1980.

In mud crabs, food location is reported to be by contact chemoreception using the dactyls of their walking legs. The anatomy of mud crab legs is typical of the family Portunidae, with the fifth pair of walking legs flattened into paddle-like structures that are used in swimming. Mud crabs have the ability to release legs or claws if handled roughly (autotomy) and can regenerate these limbs; however, it usually takes two or more moults for the regenerated limbs to regain the same size as limbs that have not been subject to autotomy.

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Part 2

Site selection

2.1 PLANNING

In all countries actively involved in mud crab aquaculture development, the national government is taking a key role in aquaculture planning to underpin national aspirations and growth targets for their respective industries. Whether it is the Fisheries Bureau, Ministry of Agriculture, China, the Department of Aquaculture, Ministry of Fisheries, Viet Nam or the Bureau of Fisheries and Aquaculture Resources, the Philippines, or similar organizations in other countries, all are implementing national policies and regulations, which will flow down to provincial areas. As a result, an individual or company seeking to develop a mud crab farming venture will need to seek local government advice on correct procedures and processes to follow to obtain the appropriate authorities, licences and permits to undertake the activity. In addition, discussing development plans with government agencies will enable potential farmers to be made aware of any incentives or regional initiatives that may assist the development and operation of their business.

2.2 ENVIRONMENTAL CONSIDERATIONS

Mud crab aquaculture is currently undertaken at relatively low densities compared with other types of pond- or pen-based aquaculture.

In Viet Nam, mud crab is just one species of many being used in integrated mangrove-aquaculture farming systems, which are focused on productive and sustainable use of mangrove ecosystems. In the Philippines, guidelines for sustainable mud crab aquaculture in mangrove pens have been developed.

Environmental assessment of an aquaculture development is undertaken by government agencies in most countries. However, the low risk of any environmental degradation from most forms of crab culture should mean that assessment of mud crabs farms is simple and relatively low-cost. For example, it may be more practical for environmental monitoring of farms based in mangroves to be undertaken in partnership between farmers and government agencies, rather than requiring sophisticated, expensive environmental impact assessments, as required for large pond-based developments involving intensive culture.

For farms involving pond construction, guidelines on how to mitigate against their environmental impact during construction and operation are provided in both the "Guidelines for constructing and maintaining aquaculture containment structures" (Anon, 2007) and the "Australian Prawn Farming Manual" (Anon, 2006).

2.3 SOCIO-ECONOMICS

Compared with more intensive types of aquaculture, mud crab farming, especially undertaken in pens or in combination with silviculture, can be a form of aquaculture requiring a relatively low investment. Some types of mud crab farming, such as crab fattening, with a high turnover of product and limited financial risk can be particularly attractive to new entrants to aquaculture.

In many countries, significant areas of mangroves have been lost to pond development for aquaculture. The potential utilization of mangrove forests for mud crab aquaculture reverses this trend, and indeed provides an added incentive for reforestation programmes. It provides a real financial benefit to such development, in addition to the role the forest plays in preventing coastal erosion and supporting inshore fishery resources.

The apparent resistance of mud crabs to diseases affecting shrimps in many parts of Southeast Asia has enabled shrimp pond infrastructure to be profitably utilized again. In addition, to avoid some of the potential pitfalls of intense shrimp culture (high input costs, high disease risk, high operating costs), polyculture of crabs with other species such as prawn, fish and algae can provide an alternative business model.

2.4 LOGISTICS

For a mud crab farming venture (or its component parts) to be viable, it is essential that logistics are such that they do not impinge on its ongoing operation. Factors to be considered include:

- transport (air, sea and road);
- availability of staff;
- accommodation;
- political stability;
- supplies;
- services available;
- power and water supply;
- proximity to markets;
- potential for flooding or other natural disasters to affect operations.

The cost of establishing and operating a mud crab farm can vary significantly depending on where it is sited; typically, the more remote the location chosen, the more expensive it is. These costs maybe offset by other factors such as cheap labour, outstanding growing conditions or other special circumstances. The preparation of a detailed business plan that takes these factors into consideration is strongly recommended in order to ensure the underlying viability of a business is not compromised by the logistics of its operation.

2.5 HATCHERY

It is rare that a hatchery is sited in an optimal location. More commonly, it is a compromise based on land availability, cost, existing infrastructure and proximity or logistical connections to grow-out areas.

The basic attributes required for a mud crab hatchery site include:

- an unpolluted source of marine seawater and freshwater;
- ability to discharge treated hatchery wastewater streams;
- a site with land suitable for construction of hatchery buildings;
- access to reasonable transport arrangements for staff and products.

The more oceanic the source of marine water, the better, as this reflects the offshore water conditions under which mud crab eggs hatch naturally. Modern water filtration and treatment systems enable a range of marine water sources to be used, although significant pollution is difficult to overcome.

The availability of power from a grid minimizes electricity costs compared with operating generators.

2.6 GROW-OUT

2.6.1 Ponds

Ponds designed for shrimp or fish, with a water depth of 80–120 cm, are also suitable for farming mud crab.

For earthen pond mud crab farming developments, the physical prerequisites for a good site are the same as for shrimp. To quote from the *Australian Prawn Farming Manual* (Anon, 2006):

"*The optimum topography for prawn (shrimp) farming is flat land that is less than one kilometre from access to estuarine or marine water, with elevations of more than 1 metre but not more than 10 metres above the highest astronomical tide (HAT) level. Ponds constructed in land less than 1 metre above HAT cannot be drain harvested during high tides, whilst very elevated sites require more energy for pumping and hence impose higher costs.*"

The properties of soil for pond construction are all important, especially as pond construction is the largest capital expense of a commercial operation. Good soil can minimize maintenance, repair, leakage and related pumping costs. Physical and chemical properties of soil should be assessed. The *Guidelines for constructing and maintaining aquaculture containment structure* contains comprehensive advice on design, construction and maintenance of operational and water storage ponds for aquaculture, including advice on soil testing (Anon, 2007).

2.6.2 Mangrove pens

The best sites for construction of mud crab mangrove pens are in areas already known (either currently or historically) for their good production of mud crabs from a wild fishery. This ensures there is no fundamental reason why the area should not support mud crab aquaculture.

Areas with relatively low tidal ranges are preferred. From a practical perspective, if there is an extreme tidal range, pen construction would need to be higher to contain crabs on high tides and mechanically stronger to withstand higher current regimes.

When choosing an appropriate area to construct a mangrove pen, low- to medium-density mangroves are preferred to extremely dense mangroves. This is because denser stands of mangrove will be more difficult to construct pens in.

Mud crab farming and wild fishing can coexist. Critical in the development of such sites is community consultation to ensure that only a limited, agreed area of the total area covered by a mud crab fishery is utilized for farming.

The close proximity of mangrove pens to coastal villages has advantages and disadvantages. The closer they are to the residence of the farmer, the easier it is to work them (i.e. feed, monitor and harvest) and to provide security from poaching. Conversely, the closer they are to human habitation, the greater the risk of poaching and the potential for pollution.

Crab fishers may well be prime candidates for mud crab farming development, as they are already familiar in handling crabs, understand how to care for the harvested product and have existing supply chains the product can be fed into.

2.6.3 Silviculture and canal

Large reforestation projects for mangroves, involving silviculture, are typically undertaken by government organizations. Arrangements for leasing areas for mud crab aquaculture are normally undertaken on a community basis.

If a variety of silviculture areas are available for lease for farming, those with larger mangroves will likely have more natural feed associated with their more advanced root systems and so would be preferred for farming.

2.6.4 Cellular systems

Cellular systems, where crabs are kept in individual containers, can be used for fattening, grow-out or soft-shell production.

Crab fattening systems can either be river, coastal or pond-based. Water quality is essential for such operations, so this should be a critical factor in establishing such a business. Crabs are kept in high densities, in close proximity to each other, so oxygen demand will be higher than in low-density grow-out systems. For river or coastal systems, a good flow of water is essential to maintain good oxygen levels. In ponds, water flow and aeration are both options that can be used to maintain oxygen at acceptable levels (>5 mg/litre).

For cellular systems involving recirculation systems within buildings, for fattening, soft-shell crab production or grow-out, the site requirements are quite different. Such recirculation systems require access to good-quality marine and freshwater sources and appropriate electricity supply, as the demands of such systems are significant.

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Part 3

Basic infrastructure

3.1 WATER

Water sources utilized should be free of significant pollution and within the pH range 7.5–8.5. This pH recommendation is based on the requirements of marine shrimp, as little work has been undertaken on the effect of pH on mud crab growth and survival. For pond farms, both a brackish to marine source of water and a separate freshwater source are ideal to manage water salinity at the preferred level.

The daily requirements for a farm requiring pumped water need to be calculated, and potential pump sites examined to ensure that sufficient quantities of water will be available for the size of the farm being planned. Factors such as the availability of water for pumping at different phases of the tide will need to be included in the calculations. Similarly, the availability of freshwater resources, which vary throughout the year in response to local rainfall patterns, should be examined. Freshwater for salinity control is most likely to be required in the driest times of the year.

As mud crabs often live in areas of turbid coastal waters, high turbidity is not a major issue, with the exception of water required in hatcheries. However, the use of sand or other filtration methods can reduce highly turbid water to water suitable for hatchery and live feed production.

While mud crabs can survive a wide salinity range in culture (5–40 ppt), optimal growth appears to be in the range of 10–25 ppt for *S. serrata*, although research has not been undertaken for all species, for the entire size range of each species and certainly not from all countries where they are grown.

In Viet Nam, most coastal areas with access to brackish and marine waters are suitable for farming *S. paramamosain*, the most common mud crab in the country, particularly those around the Mekong River Delta, where salinity is from 5 to 30 ppt.

Water temperature can affect mud crab survival, particularly towards the lower end of their temperature tolerance. However, both the temperature for optimal growth and the temperatures that will affect survival will no doubt be different for the different species of mud crabs from different localities where they have adapted to the prevailing conditions. In northern Australia, optimal growth for *S. serrata* was at a temperature of 30 °C, with good growth from 25 to 35 °C.

3.2 POWER

Typically, the power consumption of a farm requiring electricity for pumping, aeration and other machinery will require three-phase electricity from a mains supply, with backup on-site electricity available from generators.

As most pond production of mud crabs is at a low density, the electricity demand from aeration and water circulators is low compared with high-density shrimp culture. For mud crabs grown in mangrove pens or within silviculture canal systems, power is only likely to be required for feed storage and crab processing activities associated with the farms' operation.

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Part 4

Hatchery design

4.1 BIOSECURITY

The design of a mud crab hatchery needs to incorporate features that provide adequate biosecurity for broodstock and larvae, as well as any live feeds cultured within the facility. Stock can be negatively affected by: water or airborne pathogenic organisms; poor hygiene (staff or equipment); and organisms that are not adequately quarantined before being brought into the hatchery.

FIGURE 4.1
Vietnamese mud carb hatchery with larval rearing tanks

COURTESY OF COLIN SHELLEY

The more biosecure a facility is, the more expensive it is to build, maintain and operate. As such, the level of security for any particular hatchery needs to be risk-based, and should be considered in terms of the cost, relative to the benefit it can provide for any particular business (Figure 4.1). Experience to date in the hatchery culture of mud crabs indicates that a relatively high level of hygiene and general biosecurity is required to obtain consistently high larval survival and production of crablets to feed into the nursery phase of culture.

The mud crab hatchery design should ensure that all functional areas are adequately separated to minimize the risk of pathogens spreading between different parts of the operation. Broodstock, hatching tanks, larval rearing and live food areas need to be treated as separate units from a biosecurity perspective. It is also worth mentioning that areas where equipment is cleaned and sterilized should be away from operational areas in order to minimize the risk of contamination by aerosol. Design and operational guidelines should minimize staff movement between areas. Staff that are required to move between functional areas should clean or sterilize their hands and footwear to minimize transmission of pathogens.

As a high level of hygiene is required throughout the seed production cycle, the facilities need to be designed to ensure that wastewaters are efficiently removed from the husbandry areas. This means that effluent goes directly into drainpipes, floors subject to wetting drain well, and all open drains and effluent pipes have sufficient fall to completely drain. These characteristics are critical to ensuring that organic wastes and contaminated waters do not contribute to the rapid buildup of pathogenic organisms within the facility.

The hatchery design and operation schedule should allow for regular shutdown periods during which time thorough cleaning, disinfection and dry-out for a couple of weeks is conducted. This should include the flushing, disinfection and dry-out of all pipe work.

Pathogens that have been identified as affecting potential mud crab broodstock and larvae include a range of parasites, fungi, bacteria and viruses. Some diseases of mud crab of unknown aetiology have also been observed, and fouling organisms have been demonstrated to affect the integrity of the shell of broodstock mud crabs.

FIGURE 4.2
Bank of automated sand filters at the Darwin Aquaculture Centre

COURTESY OF COLIN SHELLEY

4.2 WATER TREATMENT

A range of water treatments can be used in mud crab hatcheries to minimize the risk of water-borne pathogens in water supplied to stock including filtration, ultraviolet (UV) sterilization, chemical treatment, ageing of water and ozone treatment. Often, more than one treatment method is used.

Water treatment requirements can vary by local conditions and the use of the water. In areas prone to bacterial or other water-borne issues, the treatment system will need to achieve a high level of water remediation. In this case, filtration should be followed by another step that eliminates the microbiological community, such as chlorination/dechlorination, microbial conditioning by ageing or UV or ozone treatment.

High water hygiene is particularly important for larval culture and production of live feeds such as algae, rotifers and *Artemia*. It is recommended that all water used for these purposes receive some form of antimicrobial treatment. A practical treatment system of cartridge filters followed by UV sterilization achieves a high level of particulate removal and disinfection under constant flow. For hatcheries with access to high-quality seawater, sand filtration alone may be sufficient for the broodstock maturation component of the production system.

All water sources, both freshwater and seawater, entering a mud crab hatchery need to be filtered (Figure 4.2). Domestic freshwater supply should be carbon filtered to ensure that any chemicals (e.g. chlorine) used to treat the domestic supply are removed.

4.3 BROODSTOCK

Keeping mud crab broodstock healthy, well fed and stress-free is essential for successful larval production. The facility should have tanks for initial treatment of incoming broodstock, tanks for holding broodstock and spawning tanks.

All broodstock husbandry steps should have capacity for temperature control if ambient temperature varies diurnally more than 2 °C or goes outside the optimal range. The highest level of temperature control is required for the incubation and hatching steps. Immersion heaters can be used but electrical cables need to be protected from damage by the crabs.

The broodstock are typically held in a maturation tank for a period of several weeks or more. Under adequate conditions, the broodstock can be held communally at up to $1.5/m^2$ and typically large (>10 m^3), shallow (80–100 cm deep) tanks are used.

It has been found that keeping mud crab broodstock in low light conditions appears to minimize stress levels, which in turn leads to better reproductive performance. Therefore, broodstock need to be housed in facilities constructed so that light levels can be kept low, or existing facilities need to use shade cloth or other similar interventions to enable a low light regime to be established. The inclusion of shelters in the broodstock tank provides refuge for the crabs that may further minimize stress and fighting among the stock.

Adult mud crabs are excellent escape artists. Water, air supply or heating elements provide crabs with an opportunity to pull themselves out of tanks. Often, broodstock areas will have some sort of fencing around them to ensure that valuable broodstock cannot walk out of the facility if they escape from the tanks. As mud crabs are able to escape from some plastic mesh cages by breaking the strands with their claws, the fencing should be of a suitable material.

Female mud crabs require access to a sandy bottom to spawn their eggs successfully. While mud crabs can be kept in tanks that have sand bottoms, either on the tank floor itself or an aerated raised floor (Figure 4.3), such tanks are relatively difficult to maintain. All that is required is a sand tray (Figure 4.4), so that a female that is about to spawn can access the sand when she needs to. The female will excavate a shallow depression in the sediment and, by extending her abdomen over it, create a chamber that allows extruded eggs to attach successfully to the setae of her pleopods. When performed successfully, the mother crab can attach several million or more tiny eggs under her abdomen with very little loss. Failure to provide sand to broodstock tanks will result in poor, often aborted, spawnings and low hatching rates should the hatching be successful.

Maintenance of hygiene is very important to successful broodstock maturation, and uneaten feed and waste material need to be regularly removed. This is typically achieved by the use of nets and siphons. Mud crab broodstock consume a large quantity of fresh diets, so a high level of water renewal per day is required in order to maintain water quality conditions. Where water use is restricted, a recirculating system incorporating at least particulate removal and biofiltration can be used. A foam fractionator and UV chamber will also assist water quality maintenance (Figure 4.5).

4.4 INCUBATION AND HATCHING

Once a female spawns and has an egg mass under her tail, she should be transferred to an incubation system where the water quality and hygiene conditions can be controlled to a high level. Typically, females are put into a hatching tank, with just one crab per hatching tank, so that larvae from each female can be monitored. A separate system is required for incubation because the egg mass is highly susceptible to parasitic, bacterial and fungal infection. Incubation tanks can

FIGURE 4.3
Tank for holding mud crab broodstock with an aerated sand pit for crab spawning

COURTESY OF DAVID MANN

FIGURE 4.4
Female *Scylla serrata* spawning eggs onto sand in sand tray in broodstock tank at the Darwin Aquaculture Centre

COURTESY OF GRAHAM WILLIAMS

FIGURE 4.5
A recirculating mud crab broodstock tank

COURTESY OF DAVID MANN

FIGURE 4.6
An individual hatching tank for mud crabs

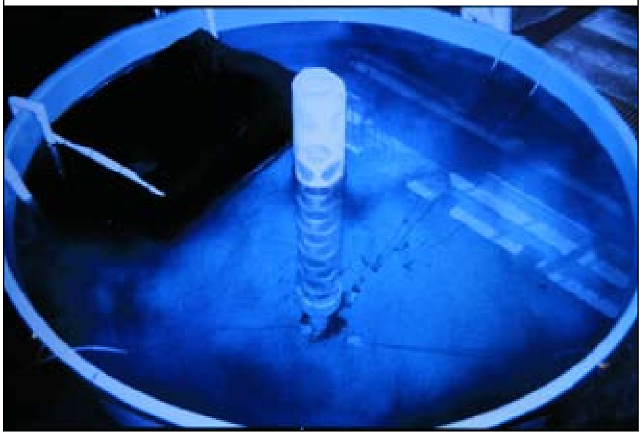

COURTESY OF DAVID MANN

FIGURE 4.7
A mud crab hatchery with ventilation provided by windows, doors and vents, with tanks that are wrapped in insulation to assist in temperature control


COURTESY OF COLIN SHELLEY

be relatively small, 100–500 litres, and, generally, several are required in a hatchery to accommodate multiple spawners held individually (Figure 4.6). During the egg incubation period, the mother crab does not require feeding, which means that there is far less waste produced and maintenance of a high level of hygiene and water quality is achieved by simple aeration and modest flow through of seawater treated to the same level as used in the hatchery.

In some locations, fungal infection is very difficult to prevent, and antimicrobial treatment of the mother and the eggs, such as a formalin bath, may be required to control it. The egg mass should be inspected regularly to identify infections and monitor egg development.

The incubation tank can be used for hatching and collection of the newly hatched larvae, but because of the very large number of larvae that hatch at once, it is recommended that a separate hatching tank of 400–1 000 litres is used. This tank requires a very high level of water treatment, as newly hatched larvae are susceptible to a range of virulent bacteria and fungi.

4.5 LARVAL REARING

The larval rearing section of a hatchery does not require the very low light levels of the broodstock component of the hatchery, but direct strong sunlight should be avoided. Mud crab larvae have been found to eat more at light levels of 1 000–6 000 lux, while below 1 000 lux, larvae both eat less and have increased mortality rates. As crab larvae exposed to 24-hour light exhibit decreased survival, compared with a 12-hour light/dark cycle, natural lighting should be the primary light source for larval rearing areas.

The larval rearing areas should be well ventilated, with a reasonably high ceiling to minimize humidity (Figure 4.7). There should also be adequate space between tanks and equipment to facilitate operation and provide access for equipment to be removed or serviced. Adequate physical separation from broodstock and feed production areas is required in order to minimize aerosol drift and maintain a high standard of biosecurity. Appropriately located walls, or barriers of some sort of sheeting, can assist in separation. When tanks are not being examined, they can be covered with plastic or similar sheeting (Figure 4.8). This reduces temperature fluctuation in tanks, in addition to controlling aerosol sprays.

Larval rearing tanks of various designs have been used to culture mud crab larvae, including circular tanks with a conical base, hemispherical round tanks, parabolic tanks and rectangular tanks.

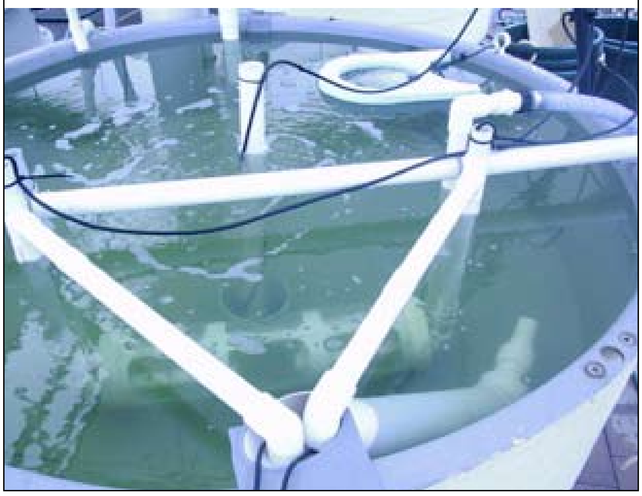
The colour of the tank in which mud crab larvae are grown has been shown to have a major impact on survival. Larvae grown in black tanks have significantly higher survival rates than any other tanks, with increasing larval survival recorded in increasingly darkly coloured tanks.

The total number and size of larval tanks required for a hatchery depends on a number of parameters, including: larval stocking density; expected survival rates between each of the five zoeal stages, the megalopa stage, through the final metamorphosis to crablet; the number of batches per year required; the number of crablets per batch; and the annual target for production of crablets. For large hatcheries, a modular approach to hatchery construction may be considered, where the design is replicated one or more times. Having duplicated (or replicated) hatchery facilities has a number of advantages.

FIGURE 4.8
Larval rearing tanks covered with plastic to control aerosol contamination and assist in temperature control

COURTESY OF DAVID MANN

FIGURE 4.9
Larval tank with heater inside a sleeve to prevent direct contact between heater and larvae



COURTESY OF GRAHAM WILLIAMS

If one of the two hatcheries experiences production problems related to a pathogen or maintenance issue, production can be maintained from the second hatchery.

Dual hatcheries provide more time for cleaning and dry-out of each hatchery between batches of larvae, minimizing the risk of buildup of pathogens within the facility.

If each hatchery has its own staff, this can both encourage internal competition and allow hatchery management to refine operations by comparing the performance of each with the other through all stages of production.

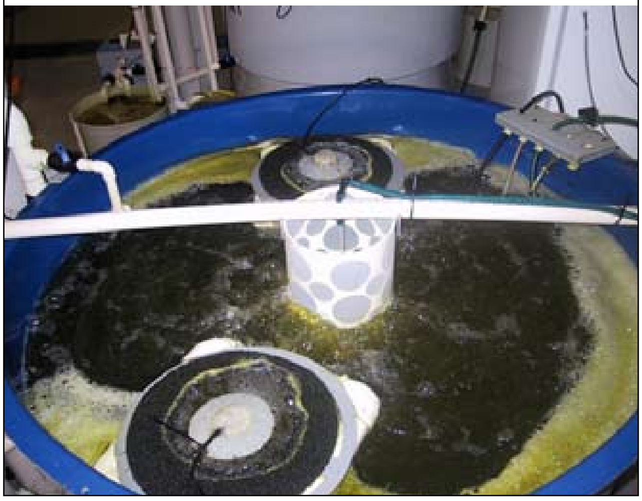
It has been demonstrated that mud crab larvae are sensitive to temperature fluctuations. As such, measures should be taken to keep water temperature as stable as possible. Standard aquaculture tanks can be wrapped in insulating materials or insulated tanks can be used (see Figure 4.7). Insulated tanks may have two layers of fibreglass or plastic, with an insulation material between them. Similarly, tanks can be covered with plastic sheeting. While improving the thermal stability of water in the tanks, this also reduces aerosols in the hatchery.

To maintain water temperature in mud crab larval rearing tanks within a narrow range (±0.5 °C), appropriately sized water heaters with a digital thermostat can be utilized. As individual larvae can be affected by direct contact with heaters, larvae can be separated from them by the use of sleeved heaters, which keep larvae away from the heating elements (Figure 4.9).

To facilitate the removal of larvae and water from the mud crab larval rearing tanks, appropriately constructed drains should be put in place, both at the base of tanks and in the floor of the larval rearing area so there is adequate space to position filter nets to recover harvested larvae.

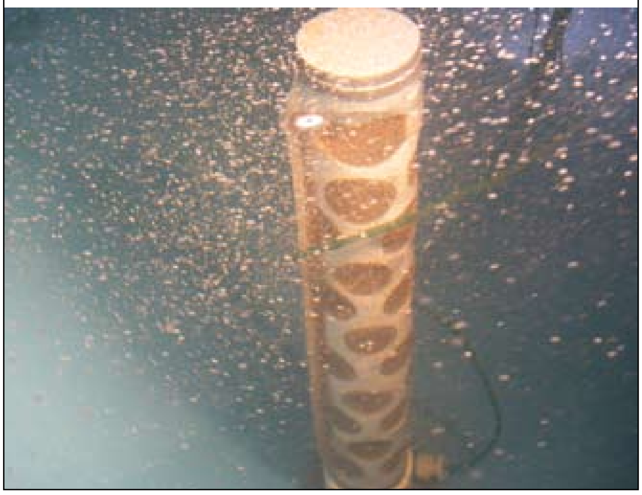
Water that has been appropriately filtered and treated for use in mud crab hatcheries is typically held in storage tanks or ponds prior to use in larval culture. Storage tanks or ponds must be sized so that sufficient water of the necessary quality can be provided throughout a larval run. Primary filtration of incoming water is usually undertaken

FIGURE 4.10
Device for collecting surface waste from larval rearing tanks seen floating on water surface (top right of photograph)



COURTESY OF EVAN NEEDHAM

FIGURE 4.11
Aeration device around central standpipe in mud crab larval rearing tank designed to keep larvae in suspension within the water column



COURTESY OF DAVID MANN

using sand filters. A range of other media and filter types can then be used to filter water for larval rearing down to 1–5 mm.

Once in storage tanks, water can be settled or aged for several days (microbial conditioning). Such treatment reduces the resident population of bacteria. This treatment can be modified by the addition of a foam fractionator, which can further reduce the organics in incoming water.

Further treatment of water to minimize bacteria in larval rearing water can be undertaken using ozone, which needs to be followed by carbon filtration to remove any residuals left after the treatment. In addition, or instead, filtration through a UV sterilizer will further reduce bacteria in incoming water.

All mud crab larval rearing tanks need to be supplied with filtered freshwater and saltwater in pipes sized to ensure that the time it takes to fill and top up tanks does not compromise production schedules. Water supply systems should be designed so that they can be flushed for cleaning as part of a regular maintenance schedule and as required if there are concerns regarding potential contamination of the water supply.

To minimize the build-up of organic waste material on the upper water surface of tanks, devices to collect and remove floating wastes should be put in each tank. One such device utilizes low-pressure air to aggregate floating surface waste, prior to removal (Figure 4.10). Similarly, equipment such as long-handled cleaning pads or wipers and siphons is required in order to remove the build-up of debris on the sides and bottom of the tank.

As it is important for mud crab larvae to stay off the walls and floors of tanks to avoid debris and potential bacterial build-up, effective aeration devices need to be supplied to mud crab larval rearing tanks. In circular conical tanks, aeration devices around the central standpipe can be effective (Figure 4.11); while in parabolic tanks, fine air bubbles from a central aeration line are best for keeping larvae in the water column.

In some systems, in-tank screens can be used to allow for flow-through of water in the larval rearing tanks or for recirculation. It is important that screen size and flow rate are matched to ensure sticking to screens does not damage larvae.

To allow for water exchange, a filter mesh screen needs to surround the outlet from the tank to retain larvae. The filter screen should therefore, have a large surface area and be of appropriate mesh size to allow passage of uneaten feed and particulate debris while not enmeshing the larvae. The mesh size can be increased as the larvae grow. For continuous water exchange, the filter screen can be installed within the tank, but for batch exchange, the filter screen can be attached to the drain hose that is temporarily submersed in the tank.

4.6 FEED PRODUCTION AREA

Live feeds utilized in mud crab larval culture commonly include microalgae, rotifers and *Artemia*, although *Artemia* is the only live feed used in some hatcheries. Areas will need to be designed for both rotifer and *Artemia* production. These should be adequately separated to reduce the potential for cross-contamination of live food and larval rearing areas.

4.6.1 Microalgae

If an algal production laboratory and tanks are required a separate area should be constructed for this purpose within or adjacent to the hatchery. Tipically when the hatchery produces its own algae, a quarantined room is used for the laboratory-scale culture production up to 10–20-litre volumes. Facilities are required for sterilizing the water and hygienically transferring algal stocks. Larger algae volumes of 500–5 000 litres, in tanks or large plastic bags, are cultured in a dedicated area indoors or outside.

However, in recent years, commercially grown microalgae, which are then concentrated for sale, can often be more cost-effective for a business than growing its own, when construction, operational and staffing costs are factored in.

4.6.2 Rotifers

There are two main methods for producing rotifers to be used as a feed for larvae:

1. Low intensity – rotifer densities range from 100 to 300/ml. Utilizes on-site cultured live algae as feed. A hatchery would require at least several tanks each with volumes of about 2 000–5 000 litres depending on hatchery size. Cultures are managed in batches or semi-continuouly for a short period.
2. High intensity – rotifer densities are typically between 500 and 1 500/ml, but can be higher. Utilizes concentrated algae pastes. Tank size is 300–1 000 litres. Requires facility for continuous water flow-through or recirculation through treatment system. Cultures are managed continuously for indefinite periods.

High-density rotifer production systems can dramatically reduce the number of rotifer production tanks required for a hatchery. An example of a high-density rotifer production system, designed to produce rotifers for fish larval production at the Darwin Aquaculture Centre (DAC), Northern Territory, Australia, which has also been adapted to produce rotifers for mud crab production in Micronesia (Federated States of) is illustrated in Figure 4.12 and described below (Schipp, Bosmans and Humphrey, 2007).

"*The high-density system utilises water exchange to manage water quality as opposed to the static, batch-culture rotifer system. Small daily water exchange is coupled with the use of a concentrated algal paste. The algal paste is enriched with essential fatty*

FIGURE 4.12
A high-density rotifer production system. The main components of the system are a rotifer tank (1 000 litres); a central 60 µm mesh screen; a floating floc trap (sediment filter), air lift and feed lines for dosing with algal paste

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acids so no further steps are needed to obtain high quality rotifers. Using the algal paste, instead of mass cultured algae, dramatically simplifies the rotifer culture process and improves its reliability, productivity and quality. In the high density system rotifers can be maintained at a density of 1 500–2 000/ml.

The relative stability of the bacterial populations, and the low numbers of harmful bacteria are features of the intensive rotifer method. When a rotifer tank is freshly started, the numbers of potentially harmful bacteria, such as Vibrio *species, rapidly increase. These pathogenic bacteria are opportunists and quickly out-compete beneficial non-pathogenic bacteria.*

Microbiological studies have shown that within two weeks of the high-density rotifer culture units being started, the bacterial population in the water stabilizes to a point where the numbers of pathogenic bacteria have declined to very low levels and beneficial (or non-harmful) bacteria proliferate.

At this point the rotifers can be directly pumped into larval rearing tanks without the requirement for time consuming rinsing to "clean" the rotifers and without adverse side effects to the larvae."

4.6.3 *Artemia*

An *Artemia* hatching system sized to meet the demand of the mud crab larval rearing facility at peak demand should be installed in close proximity to the larval rearing area to minimize technicians' work in transferring of feed to stock. *Artemia* hatching systems and methods are detailed in numerous publications.

4.7 ELECTRICAL SYSTEM

Mud crab larval hatcheries require a range of electrical appliances such as pumps, aerators, refrigerators, lighting, heaters and scientific equipment. Health and safety of staff should be the number one concern of any business. As such, the electricity system must include cut-out safety systems to ensure no staff can suffer electrocution and all electrical equipment should be routinely tested for safety compliance. Only power points specifically designed for wet areas should be used in a mud crab hatchery, which inevitably tends to be wet and humid.

During a mud crab larval run, lack of power can have catastrophic consequences if not restored quickly. Therefore, it is highly recommended that a reliable backup electrical supply from a diesel generator is available to supply electricity to essential equipment in the event of power failure.

As feeding and maintenance can be required at any time of the day, adequate lighting should be included in the hatchery's design.

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Part 5

Hatchery operation

5.1 QUARANTINE

Any potential broodstock for a mud crab hatchery should be examined carefully before they are placed in holding tanks. Only crabs that are in good condition, have no missing limbs, no necrotic spots on their shell and are not carrying any fouling or parasitic organisms should be used. Female crabs carrying an egg mass should preferably not be brought into a broodstock facility. This is because the egg mass of these crabs was spawned in the wild and, as such, its disease status would be unknown, as would be the nutritional status of the female carrying the eggs. However, berried mud crabs (females carrying an egg mass) can be utilized. If berried, those crabs carrying egg masses with brown, grey or black eggs are closest to hatching and will not have to be kept in hatching tanks for too long.

To mitigate against the risk of transferring exogenous pathogens into the hatchery, all new broodstock should be bathed in an appropriate disinfectant before placement in a broodstock tank. While formalin (40 percent formaldehyde) at 150–200 ppm for 30–60 minutes is the most common treatment, other chemicals such as potassium permanganate, malachite green and methylene blue have been used, with regular treatment every 2–3 days for 15 minutes recommended. Such treatment has been found to have no detrimental effect on either the mud crabs, their eggs or larvae. However, only treatments that are permitted for use under a country's veterinary code of practice and are managed in accordance with professional direction should be utilized, both to safeguard staff involved in larval rearing and to ensure that crablets produced from the hatchery are acceptable both to farmers and consumers.

Where fungal infection of eggs in broodstock facilities is a problem, treatment of 0.1 ppm treflan (44 percent trifuralin) every 2–3 days can be used prophylactically.

5.2 BROODSTOCK

Broodstock can be sourced from the wild, from pond-reared animals or from domesticated improved broodstock. Although wild broodstock currently have better reproductive performance than pond-reared broodstock, those reared in ponds are still of significant commercial value. This highlights the need for improved broodstock nutrition for pond-reared broodstock, so that they can match the performance of wild broodstock. While significant research has been undertaken on the genetics of mud crabs, little work has been done on domesticating stock and rearing for improved characteristics. From an operational perspective, on entering the hatchery, broodstock from any source should be treated the same.

Mud crab broodstock can be held in broodstock tanks at densities of 1–5/m^2, depending on crab size. When mature female crabs, as assessed by the appearance of the abdominal flap are sourced from the wild or from ponds, they are generally already mated and fertilized. There is, therefore, usually no need to hold male broodstock. However, when immature females are used, they will readily mate with any male provided when they moult to maturity.

The development of a mud crab's ovary can be followed by monitoring changes in its colour. This can be done by examining the area between the carapace and the first abdominal segment.

While other crustacean broodstock such as penaeid shrimp often have their eyestalk ablated to induce spawning, in mud crabs this is not usually used. Female crabs are held until the egg mass develops. As up to three egg masses can be produced by a fertilized female, ablation is a potentially wasteful process for broodstock, and depending on the size of the female used it may have a further moult, which will provide another opportunity for it to be fertilized by a male crab, and provide further egg masses.

Broodstock are usually held in full strength seawater (30–35 ppt) at temperatures from 25–32 °C. The duration of egg development is decreased as temperature is increased.

As the nutrition of mud crabs is of paramount importance, they should either be fed a good-quality fresh diet of mixed seafood (squid, fish, bivalves, marine worms), a formulated broodstock diet that supplies balanced nutrition to the stock, or a mixture of both. It has been found that an artificial diet with a total lipid content of 10 percent, in combination with a natural diet, can lead to improvement in larval production and quality. Supplements such as vitamins and minerals can be placed in components of a natural diet to ensure its completeness. Sufficient lipids and fatty acids are needed in broodstock diets to enhance gonad development, hatching and larval metamorphosis. The levels of lipid in broodstock diets are reflected in those of zoea hatched from them, and the ratio of essential n-3 and n-6 highly unsaturated fatty acids to date has been highest in larvae from broodstock fed natural diets. For *S. paramamosain,* protein has been found to be the most important source of energy for embryo development.

Mention is given to the use of other crustaceans, such as prawns in some natural diets for mud crab broodstock. While other crustaceans are certainly an important component of mud crabs' diet in the wild, the risk with this strategy is the potential transfer of crustacean-specific diseases, which may infect the broodstock and potentially their offspring. The use of other crustaceans for mud crab broodstock on this basis is not recommended, unless they can be from a source guaranteed free of disease, or treated, e.g. prawn meal, so as to remove any opportunity for pathogen transfer.

Broodstock appear to be maintained adequately with a wet diet equivalent to 5–15 percent of their body weight per day, which is typically provided over two feeds per day. As crabs are most active at night, more feed should be provided in the latest feed of the day. Broodstock feeding should be monitored and varied to meet the demands of the broodstock, so that they are fed to satiation but not to excess. If food for mud crab broodstock is put into tanks on feeding trays, this can simplify the removal of excess feed.

Waste food left in tanks after feeding should be physically removed in order to minimize bacterial build-up. The sooner this is carried out after crabs have finished actively feeding, the better. Apart from a net to remove solids, a vacuum created via a siphon is the fastest way to clean a tank effectively.

The sand used in the sand tray or on the broodstock tank floor, for crabs to spawn, should be changed routinely to minimize the risk of contamination from potential pathogens such as bacteria or fungi. Sand trays or sandy broodstock floors should be established on a false bottom plate, so that the sand can be aerated gently from below to prevent it becoming anaerobic. An airlift system that draws water through the sand bed can ensure that aerobic conditions are maintained.

All mud crab broodstock should be numbered with a tag that is easily read by technicians. This allows for all female crabs, their egg development and the larvae produced from them to be effectively monitored. To identify them individually, broodstock mud crabs can have their shells painted, a label glued on their carapace, or they can have a tag attached to an appendage.

Once a mud crab has spawned an egg mass, its development needs to be carefully monitored. Berried crabs should be removed from general broodstock tanks and placed into an individual incubation or hatching tank.

5.3 INCUBATION AND HATCHING

Once mud crabs are carrying an egg mass, they no longer need to be fed. It has been found that a 2 °C difference in broodstock water temperature can lead to problems with zoeal viability. While mud crab broodstock and larvae can be successfully kept at temperatures of 25–32 °C, it is recommended that the water for all tanks be kept within as small a temperature range as possible. Such an approach has also been found to produce improved results in shrimp hatcheries, where operators typically try to maintain temperatures within ±1 °C.

The embryonic development of *Scylla* spp. has been described with a 5, 9 or 10-point scale; however, from a practical perspective, it is critical that hatchery staff have live feed and tanks prepared in time to look after the larvae as soon as eggs hatch. To that extent, it is critical that hatchery staff are familiar with the typical time from spawning to hatching, at any given temperature, and in particular can recognize the pre-hatching phase of development. From a practical perspective, simple systems are best, so the most useful scale to use is probably the five-point scale of Thach (2009) (Table 5.1).

Egg health and development can be assessed by quick observation of the egg mass and excising several small bunches of eggs from different areas of the egg mass for observation under a low-power microscope.

TABLE 5.1
Embryonic development of *Scylla paramamosain*

Embryonic development	Description	Days after spawning	Embryo average size (mm)
Cell division	Yellow to orange	About 1 hour	270
Gastrulation	Orange	5–7	290
Nauplius	Orange; abdominal legs and eye spots start to develop	7–10	330
Nauplius with dark pigments	Grey; star-shaped spots and black oval compound eyes	10–12	340
Pre-hatching	Dark grey; heart beating; muscles begin pulsating, organs become complete; activities inside the embryo increase until the shell breaks	12–15	350

Source: Adapted from Thach, 2009.

5.4 LARVAL REARING

5.4.1 Overview

Maintaining all water quality parameters within their optimum range for each species of mud crab during larval rearing is important for success. Factors critical to successful larval rearing of mud crabs are: temperature stability; low level of organics in the water; maintaining low bacterial levels in rearing tanks; hygienic practices; the appropriate salinity; keeping larvae in suspension and consistent high-quality feeds. Where all these conditions have been met, survival rates from zoea 1 (Figure 5.1) to megalopa of over 40 percent have been obtained. While there are four species of mud crab, information to date indicates that there are more similarities than differences in the culture of the different species. It has been demonstrated that the metabolic and nutritional requirement of mud crabs can be met through the provision of nutritionally enriched live feed (rotifers and *Artemia*).

FIGURE 5.1
Zoea larvae of *Scylla serrata*

COURTESY OF GRAHAM WILLIAMS

5.4.2 Cleaning and hygiene

Hygiene within larval rearing areas needs to be kept at a high standard. All equipment to be used in larval rearing should be cleaned thoroughly and dried before use. Chlorine at 100–200 ppm is a useful cleaning agent, which can be used to soak equipment when not in use. Any equipment that is shared between tanks, e.g. metres, should be disinfected between tanks to minimize the risk of spreading pathogens between tanks.

5.4.3 Monitoring

A monitoring programme needs to be established and maintained throughout each larval rearing period. Parameters to be monitored and recorded for each larval rearing tank include:

- water temperature
- water salinity
- water treatments
- tank cleaning
- larval stage
- condition/appearance of larvae
- behaviour of larvae
- density of larvae
- in-tank feed densities
- addition of feed
- chemical treatments

5.4.4 Salinity and temperature

While the range of salinities used in mud crab larviculture varies from 22 to 35 ppt, there is some variance as to the preferred salinity throughout the process. While early zoeal stages (z1–z3) are commonly reared at salinities of 27–31 ppt, later stages (z4 to megalopa) may be reared at lower salinities (22–26 ppt). However, not all literature supports reducing salinity with increasing larval stage, with some suggesting any salinity within the range 27–31 ppt is suitable, while 27 ppt and 30 ppt are recommended optimal salinities for *S. paramamosain* by different groups. To keep the culture cycle as short as possible for *S. serrata,* a temperature range of 28–30 °C and a salinity range of 20–30 ppt has been recommended.

The preferred temperature for mud crab larviculture (25–32 °C) reflects the species tropical to subtropical distribution. However, in China, it has been reported that survival from zoea to megalopa is affected when larvae are cultured at temperatures over 30 °C.

As *Scylla* spp. are widely distributed from the Near East through to the central Pacific, it may well be that stock from different geographic locations have slightly different requirements for salinity and temperature for optimal larviculture performance. These may reflect the different environmental regimes from where broodstock have either been collected or reared. It has been documented that larvae from mud crab broodstock originating from Viet Nam and from Guangxi Province, China, had a higher survival rate cultured at 30 ppt, while those from broodstock sourced from Hainan Province, China, had their highest larval survival rate grown at 24 ppt.

5.4.5 Prophylaxis

A range of prophylactic treatments have been utilized to control both bacterial and fungal pathogens that can increase mortality rates in mud crab larval culture. The use of oxytetracycline (OTC) at 25–50 ppm has been used with some success to control bacteria in mud crab larval rearing systems. Its use, in particular, seems to have mitigated against some bacterial pathogens associated with feeding rotifers to z1–z2 larvae. As such, the use of OTC can be limited to the early stages of mud crab larval culture. In China, the antibiotics florfenicol and enrofloxacin at 1.4–2 ppm, as well as probiotics, have been used to inhibit the proliferation of pathogen bacteria in mud crab aquaculture systems, combined with increasing water flow (to dilute pathogenic bacteria).

To control fungal infections in mud crab larviculture, treatment with Treflan™ (a microtubule-disrupting chemical) (every 2 days) has been used. In addition, enhanced filtration and sterilization of incoming water can be used to reduce the incidence of fungi.

Use of any chemical treatments should only be made with appropriately registered chemicals, and under appropriate direction and/or approval from professionals trained in their use, such as veterinarians.

5.4.6 Maintaining larval water quality

Water treatment for mud crab larval rearing varies with location and availability of filtration equipment. Where the water quality of incoming seawater available to hatcheries is suboptimal, treatment by chlorination can be used, followed either by chemical de-chlorination, or aeration for 2–3 days to remove residues. Other water treatment options for mud crab larval rearing water include ozone treatment (followed by carbon filtration), UV sterilization, microfiltration and microbial conditioning.

Over the duration of a mud crab larval rearing run, waste feed and metabolites will build up in the tanks. If the tanks and water are not adequately maintained, water quality can deteriorate and bacterial levels increase, which can affect larval survival. During mud crab larval rearing, draining down tanks and replacing water with fresh high-quality water is routine. This can be undertaken as frequently as every day, to once every five days. The percentage of water changed varies from 30–70 percent of the tanks' total water volume. The frequency and volume of water exchange may be linked to the monitoring of water parameters or the level of particular pathogens, e.g. luminescent bacteria. During drain-down, tank walls can be cleaned with sterile wipes or sponges, although the ease with which this can be undertaken depends on the size of larval rearing tanks used. In addition, dead zoea, excess feeds and any wastes that settle within tanks can be removed by siphoning.

Another approach to maintain water quality in larval rearing tanks is to establish a recirculating system, which screens and treats water in tanks. Such systems need to be able to screen mud crab larvae and feed so that they remain in the tank. Such recirculating systems are not common in mud crab aquaculture at present, but as they can provide enhanced water quality compared with other systems, and mud crab larvae are sensitive to water quality, this may change in the future. An approach intermediate to water exchange or recirculation is a system set-up where water is flowed through larval rearing tanks, constantly refreshing water quality in the tanks, limiting the build-up of metabolites and the concentration of potential pathogens.

As biofilms, which can contain bacterial pathogens, can build up on the walls and floors of larval rearing tanks, it is advisable to keep larvae dispersed in the water column. To do this, gentle, non-turbulent in-tank aeration, and directional flow of water within tanks should be established. Simple airlifts, which keep larvae off the bottom of tanks, are a useful tool in this regard.

While nitrite has been shown to be toxic to mud crab larvae, the levels at which it is toxic (4–7 mg/litre for different larval stages) are approximately an order of magnitude higher than nitrite levels commonly found in mud crab larval systems (<0.5 mg/litre) and, therefore, it is of little concern to commercial hatchery operators. Similarly, mud crab larvae are not affected by the levels of ammonia routinely found in mud crab larviculture systems, which are also well below toxic levels.

5.4.7 Larval stocking

To minimize bacterial build-up in tanks containing newly hatched larvae, zoea should be collected and transferred into larval rearing tanks as soon as is practically possible.

As newly spawned zoea are phototactic, a light shone on a darkened spawning tank will attract larvae towards it and the surface of the tank. They can then be collected either via siphon or scooped with a basin into a basin for subsampling and counting prior to allocation to rearing tanks. If there is a difference in water temperature between that of the larvae and the rearing tank, the larvae should be put in basins to float on the larval rearing tank to acclimatize to the temperature of the tank they are being put into. Alternatively, a slow mixing of the waters should be undertaken to minimize the risk of temperature shock.

The recommended stocking density for mud crab z1 larvae varies from a low of 30 per litre to a maximum of 200 per litre. As crab larval production systems vary, and expected survival rates to megalopa differ, it is not surprising that a wide range of stocking densities are used.

5.4.8 Microalgae in larval rearing

While microalgae are used to feed rotifers, they are also deliberately added to mud crab larval rearing tanks. Although microalgae is seen as an optional component in some mud crab larval rearing systems, in others microalgae is deliberately maintained in larval rearing tanks at densities of 0.5–5.0 × 10^4 cells/ml.

While crab larvae may consume microalgae, their nutritional value is relatively low compared with the rotifers or *Artemia* that the larvae consume. However, eicosapentaetonic acid (EPA) (20:5n3) and docosahexaenoic acid (DHA) (22.6n3) have been shown to be essential fatty acids for mud crab larval development, which is why live feeds are fed microalgae containing them. *Nannochloropsis,* which has relatively high levels of EPA, has been linked to mass mortality, accelerated morphogenesis of larvae and abnormal moulting in *S. serrata*, as have excess levels of n-3 highly unsaturated fatty acids (n-3HUFA) generally for both *S. serrata* and *S. paramamosain*.

Microalgae are also considered to provide value to larval treatment tanks as water conditioners, in some instances maintaining enhanced water quality through microbial control.

Microalgae regularly used in mud crab larval culture systems include *Tetraselmis* and *Nannochloropsis*. Microalgal pastes and Instant Algae® of species such as *Nannochloropsis*, *Tetraselmis*, *Isochrysis* and *Thalassiosira* have also been used successfully in commercial mud crab larval rearing systems, as alternative sources of microalgae.

5.4.9 Rotifers

Among different culture systems, the density at which rotifers are recommended for early stage mud crab zoea (z1–z2) varies from 10 to 60 per millilitre. For larval culture of *S. paramamosain* in Viet Nam, most operators do not use rotifers, preferring to use umbrella stage *Artemia*, while in China, feeding rotifers at 60 per millilitre is recommended for the same species and *S. serrata*.

Tank volume and labour required to cultivate rotifers can be minimized if an intensive rotifer cultivation system can be used. The other advantages of such systems is that rotifers from them have been reported to have lower levels of bacterial pathogens than those grown at low density.

Typically, rotifers are concentrated and flushed well with clean seawater prior to dispensing them into the larval culture tanks at the required density.

A number of studies by researchers have found consensus when it comes to the use of rotifers. Improved larval survival is found when the feeding of rotifers is restricted to either the first (z1) or first two (z1–z2) larval stages.

If rotifer cultures become contaminated with copepods, treatment with the chemical chlorofos, an organochlorophosphate cholinesterase inhibitor, can eliminate them.

5.4.10 *Artemia*

The main live feed for mud crab larvae is *Artemia*. It is commonly used to feed them from z2 or z3 through the megalopa stage to settlement. They are provided to larvae at densities from 0.5 per milliltre to 15 per millilitre. In Viet Nam, umbrella stage *Artemia* are used in place of rotifers for z1–z2 larvae. However, from late z2 or z3 onwards, *Artemia* nauplii are used in all systems. While the quality of *Artemia* used in mud crab larviculture has been found to affect larval survival, *Artemia* enrichment products are commonly used to maximize their nutritional value. Larger larvae that have been hatched and grown for 5–7 days can be fed to advanced zoea (z5) and early megalopae, although newly hatched nauplii can also be used. Typically, feeding density of *Artemia* is increased with increasing larval stage, e.g. 0.5 per millilitre at z2, increasing to 3.0 per millilitre at z5 to megalopa. Megalopae can also feed on adult-sized *Artemia*. While the use of enrichment products on live feeds does not necessarily improve survival rates of mud crab larvae, it does appear to improve larval development rate, shortening the time of the larval stages. Enriching *Artemia* with high doses of vitamin C has been reported to have improved metamorphosis of z5 to megalopa, and megalopa to crab, but has yet to be quantified.

It has been demonstrated that crab larvae can complete larval development with a wide range of total energy intake, and that larvae can increase their daily feeding rates with increasing larval stages. Therefore, the total number of feed organisms provided per day to larvae needs to be increased gradually with larval stage, so that the megalopa stage accounts for 58–64 percent of the total feed uptake during the larviculture cycle.

Dramatic improvement in the bacterial loading of hatched *Artemia* can be achieved with the use of commercially available hatching chemicals, e.g. INVE Hatch Controller. The susceptibility of mud crab larvae to a range of pathogenic bacteria makes the use of such products particularly useful.

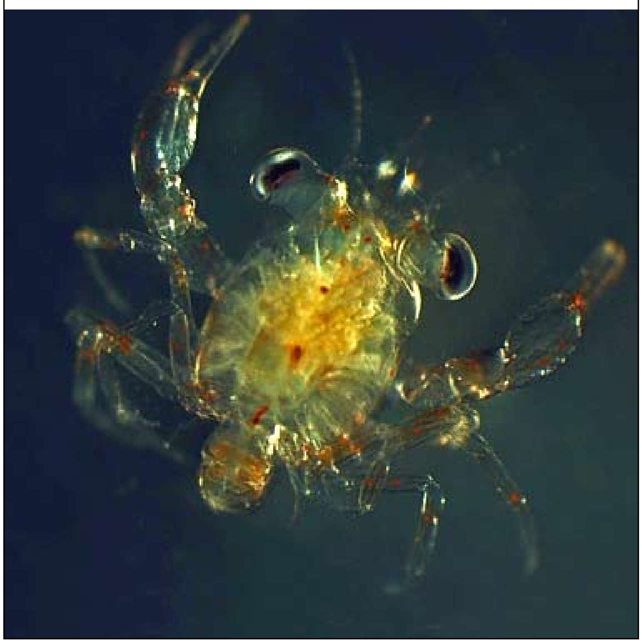
5.4.11 Supplementary feeding of larvae

Many specialist formulated feeds developed for use in shrimp hatcheries can be used successfully in mud crab hatcheries. These are used in addition to live feeds. Their usefulness depends on the particle size of the product. Some products may need to be screened to obtain the appropriate size of feed to meet the needs of a particular sized larva. It has been reported that 50–70 percent of live feed can be replaced with formulated larval feeds.

While significant work has been undertaken on the use of microbound diets for mud crab larvae, no commercially available larval feeds have yet been developed.

During the megalopa stage (Figure 5.2), some operators utilize minced bivalve or fish as supplementary feeds. As such feeds are intrinsically messy, they can easily lead to water quality issues, so their use and the quality of water if they are used need to be monitored carefully.

FIGURE 5.2
Megalopa larvae of *Scylla serrata*



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5.4.12 Feeding frequency

Larval feeds should be provided 2–3 times a day.

Typically, a substantial amount of live feeds will remain in the tank by the next feeding time. Residual rotifers and *Artemia* will have become nutritionally deficient after 24 hours and may start to die. Therefore, if the density of residual live feeds increases, it is necessary to remove a substantial proportion of them before adding the next feed. Water exchange or recirculating the tank water through an appropriately sized sieve can control levels of residual live feeds.

5.4.13 Zoea 5 to megalopa

As zoea 5 mud crab larvae metamorphose to the megalopa stage, there can be significant cannibalism by megalopae on zoea 5 larvae that have yet to go through metamorphosis. Maintaining ideal culture and food conditions throughout the larval cycle will improve the synchrony at which the larvae undertake metamorphosis and reduce the potential for cannibalism. To minimize cannibalism at this stage, it is possible to harvest megalopae as soon after metamorphosis from z5 as possible and transfer them to separate rearing tanks, by dragging screens of 2 000–2 400 mm through the larval rearing tank. A screen of this size will collect megalopae, leaving z5 larvae in the rearing tank. Separating megalopae from tanks with mixed larval populations (z5 and megalopae) can be undertaken several times a day.

5.4.14 Transportation of megalopae

Megalopae can be packaged and transported in the same fashion as postlarval shrimp or fish fingerlings in oxygenated water contained within double plastic bags. The bags should be maintained within insulated containers to minimize temperature fluctuations. Cooling transportation water a few degrees below the temperature in which the megalopae have been reared is recommended in order to minimize oxygen consumption through reducing their metabolic rate.

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Part 6

Nursery

6.1 NURSERY DESIGN OPTIONS

6.1.1 Tanks

Once megalopae have settled and metamorphosed into crablets (Figure 6.1), it is the surface area of tanks that is the most important. The simple design of mud crab nursery tanks reflects their operational needs. Commonly, nursery tanks are rectangular, with a flat base constructed from concrete (Figure 6.2) or fibreglass, with a sloping floor to a sump (simplifying drainage), and provision made for the supply of fresh, saltwater and aeration.

In nursery tanks exposed to the elements, overheating of tank water can be an issue, especially in summer months, which can lead to high mortalities of crablets. To counter this, nursery tank systems are typically covered with an overhead awning or roof to filter out direct sunlight and also prevent rain entering the tanks. Rapid changes in salinity from heavy rain could also stress crablets and potentially lead to increased mortality rates, if uncontrolled.

Various materials can be placed or suspended in nursery tanks providing three-dimensional shelter, which increases the surface area available for settled crabs. Materials that can be used include bunches of netting, leaf fronds, straw, PVC off-cuts or artificial sea grass.

FIGURE 6.1
An individual crablet, C1

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6.1.2 Net cages (hapa nets)

Square or rectangular net cages (or Hapa nets) (Figure 6.3), typically of 1–2 mm mesh opening, are set in earthen ponds, the base of the net buried into the bottom of the pond. Ponds should be used or designed so that a water depth of 80–120 cm of water can be maintained to support moderate water temperature fluctuations and steady plankton populations. Zooplankton populations should be established in the ponds to provide feed for the megalopae once they are stocked.

FIGURE 6.2
Nursery tanks for mud crabs

COURTESY OF COLIN SHELLEY

6.1.3 Earthen ponds

Ponds may be stocked with *Gracilaria*, netting, straw or other shelters to provide habitat for crablets. In China, mud is

FIGURE 6.3
Hapa nets


COURTESY OF COLIN SHELLEY

considered the best surface for megalopae to settle on to become crablets. As for net cage nursery culture of megalopae, mixed zooplankton population developed within the pond is the primary food source for the megalopae.

Nursery ponds should be surrounded, typically around their banks, by a short fence (height 20–40 cm) constructed of relatively fine mesh (1–2 cm) netting or similar to ensure crablets cannot walk away from the ponds should water conditions in them deteriorate for any reason. The fence is made more effective if the top of the net is covered with plastic sheeting, which crablets cannot climb over.

If multiple nursery areas are set up in one pond, fencing, buried into the pond floor, can be used to separate them and manage the stock in each area independently.

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Part 7

Nursery operations

To maximize the survival of megalopae during transport to nursery operations a stocking density of 50–100 per litre has been found to be optimal for transport times of up to 12 hours.

FIGURE 7.1
Three-dimensional habitat utilized in mud crab nursery system

COURTESY OF DAVID MANN

Megalopae are stocked either into tanks, net cages or earthen ponds at densities of 1–50 per litre, although some prefer to stock at a density linked to the surface area available for megalopae to settle into crablets on, e.g. 1–2 000 megalopae/m^2. It is recommended that 50–70 megalopae/m^2 be stocked into net cages in ponds. The main determinant on optimum stocking density is the size at which the crablets will be harvested. The larger the crablets that will be harvested from the nursery system, the fewer that should be stocked, as the cannibalism rate is strongly correlated with density and rapidly increases with crab size during the early crablet stages.

Nursery systems do not generally require a high level of water treatment by filtration or disinfection as late-stage megalops and crablets are tougher than the zoeal larval stages.

Survival of megalopae in net cages is reportedly higher than in earthen ponds, although this may well be a result of the ease of harvesting crablets from net cages compared with trying to retrieve them from ponds.

While some form of shelter, such as netting, mussel shells or artificial seagrass (e.g. Aquamat®), is often put in tanks, these materials are more important for crablets rather than as materials to settle on. The shelter materials provide a three-dimensional habitat (Figure 7.1) that assists in minimizing inter-crablet antagonistic behaviour, providing more areas for newly moulted crabs to hide from other crabs. The addition of habitat to nursery systems appears to improve survival at all crab densities, but has little effect on growth.

Prior to stocking of ponds, it is essential to ensure that no significant predators of megalopae or crablets are in the pond. To do this, the pond can be drained and dried, or alternatively a saponin or similar chemical can be used to kill off any animals in the pond. Any new water added to the pond should be filled through a filter net, of opening approximately 2 mm, to mitigate against any potential predators of megalopae or crablets entering the pond.

As survival of crablets in nursery systems typically decreases with time, unless action is taken to minimize the affects of cannibalism and overcrowding, it is recommended that the nursery phase of crab culture be kept as short as practical. While it is possible to grow crablets in individual containers and obtain higher survival and growth than in other systems, at present the expense of such systems, both to construct and operate, appears to outweigh their benefits.

7.1 WILD VERSUS HATCHERY-SOURCED CRABLETS

While there appears to be little difference in the performance of wild compared with hatchery-sourced crablets in terms of growth or survival, wild crablets do display more agonistic behaviour, which makes them less suitable for a farming system. The other major concern regarding the use of wild crablets is that their harvest in many countries is not sustainable, and their removal is having a negative impact on wild populations of mud crabs.

Conditioning crablets before release into farming situations appears to be advantageous, particularly for those going into mangrove pen or silviculture-canal systems, where exposure to potential predators is more likely. Hatchery-reared crablets of *S. serrata* have been reported to differ from wild crablets, both in their colour and their burying behaviour in sediments. However, after conditioning for 4–8 days on coloured tanks or dark sediments, hatchery-reared crabs difference in coloration with wild crablets was reduced, and 2–4 days exposure to sediment brought their burying behaviour up to the level of wild crablets. This demonstrated the advantages of conditioning crablets prior to release into farming systems or for stock enhancement. The ability of mud crabs to adapt to their environment by changing the colour of their shell has been reported for other *S. serrata* held in captivity.

Sorting or grading of crablets by size during the nursery phase can be undertaken. Smaller size differences between stock can help in minimizing cannibalism.

7.2 ENVIRONMENTAL PARAMETERS FOR NURSERY CULTURE

While juvenile mud crabs (crablets) can be grown successfully across a wide range of temperatures and salinities, optimal conditions for their growth and survival appear to be at 30 °C, and salinities of 10–25 ppt, while salinities of 36 ppt and 48 ppt have been reported to have a detrimental effect on crablets growth.

The duration of the megalopa stage of *S. serrata* has been reported to be shortest at a salinity of 20 ppt and a temperature of 31 °C.

7.3 FEED

Advanced *Artemia* (5 days old) at 20–25 per millilitre and formulated shrimp larval feeds are provided to the megalopa stage mud crab larvae, prior to settlement.

Once settled, formulated feeds (at present, formulated prawn starter diets as few crab-specific diets have been developed), or diets of trash fish, and/or molluscs can be used to feed crablets. On-grown *Artemia*, up to adult size, can also be fed throughout the megalops and early crablet stages.

Diets of 45–55 percent crude protein and 9–15 percent lipid appear to support optimal growth in crablets of *S. serrata*.

7.4 HARVEST OF CRABLETS

Crablets are typically harvested from nursery systems after a 3–4-week period and moved to grow-out systems having grown to over 1 cm and to weights up to 0.3 g, at the C3–C4 stage. For *S. serrata* in China, crablets are harvested earlier at C1–C2 and then transferred to ponds to grow to C7–C8, then moved again to other ponds for final grow-out.

In net cages, lift nets with feed on them can be used to attract and harvest crablets. For the final harvest from a net cage, one end of the cage can be lifted and crablets scooped from the other.

To minimize the risk of death in transit, any soft-shell, recently moulted crablets should not be transported until their shell has hardened.

7.5 TRANSPORTATION OF CRABLETS

Crablets older than C2 can be transported with or without water. Cooling crablets before transport is recommended to prevent both moulting and lower oxygen

FIGURE 7.2
Plastic container with moist sand for transporting crablets, Viet Nam

COURTESY OF COLIN SHELLEY

consumption during transport. Crablets can also be transported in water using the same method as used for post-larval shrimp or juvenile fish.

Out of water, crablets can be transported in containers on moist sand (Figure 7.2) or damp cloth, in containers that are lined and covered to minimize evaporation and resulting desiccation, while ventilated to ensure they can respire adequately. It is recommended that transport of crablets out of water should not exceed 30 hours.

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Part 8

Grow-out design options and construction

8.1 PONDS

The basic design of most earthen ponds used to culture mud crabs (Figure 8.1) is the same as that used to culture marine shrimp. In many parts of Asia, where the profitable culture of shrimp has been affected by disease or low prices, shrimp ponds have been switched over to the culture of mud crabs.

Mud crab aquaculture has seen some design innovation to reflect different culture techniques for crabs, and some that enable farmers to utilize a single pond to cater for the needs of mud crabs from different stages of the production cycle.

The comprehensive guidelines for constructing and maintaining aquaculture ponds in Queensland, Australia (see Anon, 2007), to minimize the risk of their leakage or failure, is a valuable source document for the construction of ponds suitable for mud crab farming.

FIGURE 8.1
Earthen mud crab pond with netting around the pond, China

COURTESY OF CHAOSHU ZENG

8.1.1 Stock control netting

Unlike marine shrimp, mud crabs can leave water and spend considerable periods of time on land. As a result, if a barrier of some type did not surround a mud crab aquaculture pond, stock would be able to walk out of the pond, which would be a direct financial loss to the farmer. To counter this mud crab behaviour, netting typically surrounds mud crab culture ponds (Figures 8.1 and 8.2). Netting height may vary from 20 to 50 cm in height above the top of the pond. The netting is typically supported by posts and may be topped with plastic. The plastic topping is added as mud crabs are good climbers and they can climb up netting, but are unable to climb up clear plastic sheeting.

A variation in design for the stock control netting is that it can be constructed along the inner top slope of the pond, at such an angle that a crab would have to hang upside down to climb over the net to escape from the pond. For anything larger than a juvenile size crab, this is usually not possible. However, from a maintenance

FIGURE 8.2
Earthen pond with simple net structure to prevent mud crabs walking out of the pond

COURTESY OF COLIN SHELLEY

FIGURE 8.3
Mangrove pen with bamboo fence

COURTESY OF CHAOSHU ZENG

FIGURE 8.4
Mangrove pen with net fence and wooden supports

COURTESY OF COLIN SHELLEY

FIGURE 8.5
Wooden nursery structure within a mangrove pen to hold small crablets

COURTESY OF COLIN SHELLEY

perspective, netting around the top of the pond is easier to maintain, as access is simpler for staff. Working inside the inner top slope of the pond can cause unnecessary erosion to the bank of the pond depending on its construction and soil type.

8.1.2 Dry raised feeding platforms or mounds

Some ponds have been designed with raised areas or mounds within them. The concept is that this enables crabs to leave the pond from time to time, to mimic the periodic exposure that occurs in their natural environment. Such platforms have also been used as feeding stations for crabs.

Such designs reduce the pond area underwater, and may increase the upkeep of the ponds compared with a typical "shrimp" style pond. As mud crab behaviour is driven in part by the tidal cycle, ponds with raised platforms might perform best if water in the ponds also varied in height with the tide. There appear to have been no published data that demonstrate any benefits from this design over conventional shrimp style ponds.

8.2 MANGROVE PENS

As mangrove forests are the native habitat of mud crabs for most of their juvenile and adult life, it is not surprising that farming systems have been developed that utilize their preference.

Mangrove pens are designed to retain mud crab farm stock within a specific area of mangrove so that they can be fed, their growth monitored and ownership clearly delineated.

Pens may be constructed entirely of wood or plant fencing (Figure 8.3) (e.g. bamboo, or palm trunks), or of netting with wooden supports (Figure 8.4). The netting or spacing between the fencing needs to be small enough to ensure that the smallest sized crab placed in the pen cannot escape, typically 1–2 cm mesh.

Pens may have an inner nursery structure (Figure 8.5) that can be used to hold very small stock for a limited period of time, until they are large enough to be retained in the main pen structure. The inner pen structure in such a design would be constructed of fencing or netting with a smaller opening to retain the smaller stock. This can be considered to be either part of the nursery system or preliminary grow-out stage. The inner pen structure enables smaller stock to be more intensively managed, until they are of sufficient size to be let into the larger pen.

The height of the pens must be higher than maximum king tides, so that stock cannot simply swim out of the pen on such tides. Tide tables and local knowledge should be used to establish the appropriate height to construct the pens.

Access to the pens can be by various means. For solidly constructed pens, access can be by doors constructed in the walls, or via walkways (Figure 8.6) constructed to provide access to the pens at any stage of the tide. While such structures provide optimal access, their construction is an additional expense that may be avoided depending on factors such as the type of mud, access to the pen and maximum tidal variation in the area. For pens constructed primarily of netting, overlapping panels of netting can be affixed to allow access.

Similarly to ponds, it is preferable that their upper edge be lined with plastic or a similar material that prevents mud crabs from climbing out of the pen (Figure 8.7).

FIGURE 8.6
Mangrove pen with wooden walkway

COURTESY OF CHAOSHU ZENG

FIGURE 8.7
Mangrove pen wall constructed of net with plastic upper edge to prevent crabs climbing out

COURTESY OF COLIN SHELLEY

8.2.1 Mangrove pen construction

The walls of mud crab mangrove pens need to be buried in the mud (30–60 cm) to minimize the risk of mud crabs burrowing under the walls of the pens.

Pens are commonly constructed with vertical support posts every 3 m, and horizontal bracing structures to support the walls.

To maximize the longevity of pen structures, posts should be made from wood that is most resistant to marine borers or treated to reduce their impact. Posts covered in plastic (Figure 8.8) or a plastic sleeve to protect the wood, or posts constructed from a synthetic material, will provide the maximum longevity. However, such posts are often considerably more expensive and may be prohibitive for many operations.

FIGURE 8.8
Wooden posts with synthetic cover to prevent marine organisms boring into them

COURTESY OF WOOD-SHIELD PTY LTD

Research undertaken in the Philippines has identified a number of simple guidelines that minimize environmental impact both during construction and then operation. Pens should be constructed to minimize damage to mangrove roots, to preserve the health of the trees. In addition, pens need to be constructed and maintained so that they do not change natural drainage and flow of water through the mangroves. If drainage and flow are altered, this can lead to the death of mangroves that are used to, and require, high and low tides for good health. When designed and constructed according to these guidelines, mud crab mangrove pens have been demonstrated to be ecologically sustainable.

Mud crab mangrove pens put a commercial value on the mangroves, which can be considered to complement conservation measures to preserve and maintain healthy mangrove forests. In many areas without this additional value, their primary value may be perceived to be for use as fuelwood, charcoal production or for use in construction.

Some mud crab pen construction includes the construction of ditches within them. The idea is that water will be held in them at low tide so that crabs can stay immersed when tides are out. One extension manual suggests that 20–30 percent of the area of a pen should consist of such ditches.

8.3 CRAB FATTENING

After moulting, crab musculature takes some time to grow to fill its new shell, so the crab is referred to as “empty”, “thin” or a “water crab”. If such a crab is cooked, it will appear to have little meat and lots of water in it, a most disappointing experience for a consumer.

Mud crab fattening refers to the process whereby, “empty crabs”, identified at harvest (either from the wild or from farm stock), are held and fed for a period, often of only a few weeks, until they are full of meat and ready to market.

FIGURE 8.9
Individual containers for mud crab fattening

COURTESY OF DAVID MANN

8.3.1 Pens, tanks and cages for crab fattening

Various structures, including cages, floating cages, ponds or tanks (Figure 8.9), can be utilized to hold mud crabs for relatively short periods of time for fattening. As long as the mud crabs are held in water of suitable quality, fed regularly and precautions are taken to minimize disease, crabs for fattening can be held at reasonably high densities. Fattening operations may be constructed within an existing pond or pen, a tidal river or creek. More sophisticated systems can be operated in flow through or recirculating land-based aquaculture facilities.

8.4 SILVICULTURE AND CANAL SYSTEMS

In many Asian and Indo-Pacific nations, significant areas of mangrove forests have been damaged, removed or degraded over the decades. To counter this, large areas of new mangrove forests have been planted in many countries, including Indonesia, the Philippines and Viet Nam. In addition to the lumber they will produce in time, these new forests are often constructed around canal systems to ensure adequate circulation and drainage. Such systems have also provided an opportunity for low-intensity culture of mud crabs, both in canals and within the new mangrove forests themselves. Areas of the forest may be fenced to minimize escape of mud crabs stocked into the area (Figure 8.10), or if a communal approach is taken to the culture of crabs within the forest, there may be no structures to retain stock. This is because it is assumed that the community will share the benefits of stocking the area with crabs.

FIGURE 8.10
Silviculture system with net fence to retain mud crabs

COURTESY OF NGHIA TRUONG TRONG

8.5 CELLULAR SYSTEMS

Some investment has been made in developing cellular systems to culture mud crabs, following research and development that identified their potential. In cellular systems, crabs are held individually in containers (or “cells”) (Figure 8.11) to mitigate against the risk of cannibalism and in an attempt to provide optimal conditions for growth. While such systems have been developed, their primary use has been in the culture of soft-shell crabs. In these systems, small mud crabs (80–120 g) are held in isolation until they moult, at which point they are either chilled or frozen before their new outer shell can harden. Typically, crabs are only held in the system for a few weeks until they moult.

FIGURE 8.11
A cellular mud crab system with individual containers for each crab

COURTESY OF DAVID MANN

Systems have been built (Figure 8.12) with a variety of technological systems incorporated into them to minimize labour and maximize automation. Probably the most sophisticated system designed to date includes cameras linked to a computer system that regularly scans cells to see if one or two crabs are in each cell. Two crabs in a scan means the crab has moulted, leaving an empty shell and a soft-shell crab that needs to be harvested. This system also includes a sophisticated water recirculation system.

FIGURE 8.12
Cellular soft-shell crab system

COURTESY OF MAYMAT NOELWIN

Crabs for such systems are obtained either from wild harvest or farmed crabs. The capital-intensive nature of such systems appears to have made their use for the whole grow-out process prohibitive at this time. Farmers have focused on soft-shell production to maximize the return on their investment, using a high throughput of stock. A manual has been produced that provides comprehensive technical and practical details on soft-shell mud crab farming (Quinitio and Lwin, 2009).

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Part 9

Grow-out operations

9.1 PONDS

9.1.1 Preparation for stocking

Prior to stocking, after the previous harvest, ponds should be dried out for several weeks and any repairs undertaken. This assists in ensuring any unwanted species are removed from the pond that may be competitors for feed fed to crabs or predate on crablets. If a layer of sludge is left in the pond after the previous crop, this should be removed for storage and remediation.

Turning over the soil in the bottom of the pond, or tilling, can assist in preparing the pond for the next crop. This helps in the breakdown of organic residues and release of nutrients.

Tilling can be combined with the addition of lime to pond floors. Liming can be used to improve the pH of pond sediments, accelerate decomposition of organic matter and improve fertilizer response.

Some ponds used in crab production may be difficult to drain, and may be restocked after harvest without draining. To eradicate competitors or predators for mud crabs from the pond, the water should be treated. Appropriate treatments permitted for such use should be obtained from aquaculture or farming authorities within the country. Possible treatments include tea seed cake and rotenone.

Brackish water or saltwater being used to fill a mud crab pond should be filtered through a small mesh "sock" or "bag" of approximately 120 µm mesh to reduce the risk of other species entering the pond. If other species become established in the pond, they may predate upon introduced mud crab stock, consume their feed and use up oxygen in the water while providing no increase in crop value.

As mud crab culture in low salinity water (5–12 ppt) has been linked to low survival of stock and delayed moulting, ponds should be stocked with brackish to fully saline water (10–35 ppt).

The growth of *S. serrata* crablets in Australia has been demonstrated to be optimal at salinities of 10–25 ppt; however, the optimal salinity regime for an entire crop has yet to be published. While in Viet Nam crabs can grow under a wide salinity range from 5 to >35 ppt, juvenile crabs are often held in brackish water (15–25 ppt) for optimal growth.

For further detailed information on pond preparation, the *Australian Prawn Farming Manual* is recommended (Anon, 2006).

9.1.2 Stocking for monoculture

A wide range of stocking densities has been trialled for mud crabs. Compared with penaeid shrimp, mud crabs are stocked at relatively low densities (0.5–1.5 crabs/m^2) with survival rates as high as 67 percent. These stocking densities reflect both the size of individual mud crabs and their tendency to cannibalistic behaviour. However, stocking at higher rates of 1–3 crabs/m^2 has been used with survival from 40 to 60 percent. Stocking mud crabs from 0.5 to 3.0 crabs/m^2 is considered semi-intensive, compared with extensive mud crab culture commonly practised in Viet Nam.

When farming was solely based on collection of mud crabs from the wild, stocking rates used in Viet Nam were as low as 0.1–0.2 crabs/m^2 for *S. paramamosain*, but now with the availability of hatchery produced crablets stocking is commonly 1.0–1.5 crabs/m^2

with a size range of 1.2–2 cm CW. It has been demonstrated that semi-intensive operation of ponds are more profitable than extensive systems and that stocking size, as well as feed used have a significant effect on the final bodyweight of mud crabs.

Survival rates of mud crabs in ponds vary considerably, no doubt reflecting husbandry practices, water quality parameters and the quality of stock, with reports ranging to highs of over 70 percent.

The monoculture of mud crabs can be undertaken in rotation with shrimp culture.

As mud crabs are naturally cannibalistic, it is important to try and minimize this. One approach worthy of adoption is to stock ponds with crablets of as near the same size as possible, to minimize the risk of larger crabs feeding on smaller ones.

9.1.3 Stocking for monosex monoculture

It has been reported that male crabs attain a significantly higher final weight than female crabs. As crabs can usually be sexually differentiated by the time they are at the C4–C6 stage by examination of the shape of their abdominal segments (see Figure 1.5), ponds can be stocked for monosex culture from advanced crablets. Stocking with monosex mud crabs can simplify post-harvest processing and may minimize aggressive behaviour between crabs associated with sexually maturity.

Another potential advantage of monosex culture is that at least one study has found that survival of monosex mud crabs was significantly higher than among mixed sex crabs.

9.1.4 Stocking for polyculture

Mud crabs can be polycultured successfully with species including milkfish, grass shrimp, *Litopenaeus vannamei*, tiger shrimp (*Penaeus monodon)*, *Gracilaria* spp. and other marine species. Stocking is typically at densities below those used for monoculture of either species.

Survival rates for *S. serrata* grown in polyculture systems have been reported from 27 to 40 percent, with shrimp from as low as 8 percent to a high of 79 percent.

In Viet Nam, in extensive shrimp and crab polyculture, crabs are stocked 10–15 days after shrimp are stocked, at 0.01–0.2 crabs/m^2. Low survival rates of 15–30 percent have been reported.

In polyculture systems in the Philippines, mud crab juveniles may be stocked at 5 000–10 000 per hectare in combination with milkfish fingerlings at 500–2 500 per hectare or shrimp post-larvae at 10 000–20 000 per hectare.

In China, polyculture of mud crabs with *Penaeus monodon* has been undertaken with mud crabs stocked at 7 500 per hectare and shrimp at 9×10^4 per hectare.

9.1.5 Stocking operations

Preferably, all stock should arrive at a farm with health checks already completed. Even with a clean bill of health, the quality of crablets (and juvenile stages of other species being stocked for polyculture) must be assessed for quality prior to stocking.

To assess the quality of a batch of crablets one should examine the following criteria:

- Visual health – pick a subsample of crablets and examine for fouling, unusual coloration, damage to legs or claws.
- Size variation – while crablets in any batch may be at different moult stages, size variation should be minimal. Extreme variation in size indicates batches may have been combined. Too large a variation in size increases the likelihood of losses to cannibalism.
- Activity – if crablets have been transported to farm at temperatures less than optimal, they may be sluggish. After equilibrating to ambient temperature, they should be actively walking or swimming.

FIGURE 9.1
Feeding tray to monitor feed consumption in mud crab pond

COURTESY OF COLIN SHELLEY

On arrival, crablets (or representative samples of each batch) should be counted to ensure the order has been fulfilled.

Crablets can be transported to a grow-out facility with or without water. If packed in water they may be cooled to 22–24 °C to prevent moulting on the way to the farm and to lower oxygen consumption. At the farm, crablets should be put in basins (or similar containers) with a small amount of water from the pond for which they are intended to acclimatize. Once acclimatized to the temperature of the water and its salinity, they can be released into the pond. For larger ponds, distributing them from several different points around the pond to assist in distributing them evenly around the pond is recommended.

9.1.6 Monitoring

As in any farming venture, monitoring various parameters related to the crop will, over time, develop into a knowledge management system that can assist the farmer in decision-making and operating a more profitable enterprise.

Parameters that should be monitored include:

- water quality;
- feed consumption (Figure 9.1);
- mud crab growth and survival; and
- mud crab health.

While some of the optimal water parameters for mud crab farming can still be considered to be under development, such have been developed for shrimp, another crustacean similarly farmed in subtropical and tropical environments. Table 9.1 lists optimal water quality parameters for mud crabs, but if not yet known, those for *Penaeus monodon* are used to provide guidance to farmers.

TABLE 9.1
Suggested water quality parameters for mud crab pond management

Parameter	Optimal range	Sampling frequency
Dissolved oxygen	>5 ppm* (mud crabs tolerant of low oxygen levels)	Twice daily
pH	7.5–9.0; <0.5 variation diurnally; optimal approx. 7.8*	Twice daily
Temperature	25–35 °C	Maximum and minimum weekly
Salinity	10–25 ppt for crablets	Weekly
Total ammonia nitrogen (TAN)	<3 ppm* (crablets high ammonia tolerance)	Daily as required
Un-ionized ammonia (NH_3)	<0.25 ppm* (crablets high ammonia tolerance)	Daily as required
Nitrite (NO_2)	<10 ppm at salinities >15 ppt; <5 ppm at salinities <15 ppt*	Daily as required
Alkalinity	>80 ppm (ideally 120 ppm)*	Daily as required
Hardness	>2 000 ppm*	Daily as required
Hydrogen sulphide	<0.1 ppm*	Weekly
Secchi disc (turbidity)	20–30 cm*	Daily

* Range as for *Penaeus monodon*.

Source: Adapted from the *Australian Prawn Farming Manual* (Anon, 2006).

FIGURE 9.2
Low-value/trash fish used as mud crab feed, the Philippines

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FIGURE 9.3
Tuna waste to be used for crab culture, Fiji

COURTESY OF COLIN SHELLEY

FIGURE 9.4
Cockles used as crab feed, Viet Nam

COURTESY OF COLIN SHELLEY

9.1.7 Pond operations

The oxygen concentration of brackish water or saltwater in ponds should be kept above 3 ppm or preferably at 5 ppm.

As mud crabs are currently farmed at densities that can be considered semi-intensive, maintaining reasonable levels of oxygen is usually not an issue. However, it is worth having access to paddle wheels or aerators for ponds to counter events that can occur suddenly, lowering oxygen levels, such as algal crashes within the water column.

9.1.8 Feeds

Mud crabs can be successfully raised on a variety of diets including low-value/trash fish (Figure 9.2), slaughter wastes, fish wastes (Figure 9.3), horse mussels, brown mussels, brackish water snails, shrimp heads, golden snails (*Pomacea canaliculata*), telescope snails (*Telescopium telescopium*), small bivalves (*Potamorcorbula* spp.) (Figure 9.4), animal hides, entrails, kitchen leftovers and formulated shrimp feeds.

Development of formulated feeds for mud crabs is likely to become increasingly important as trash fish and other wild resources come under increasing pressure for use as feed for various types of aquaculture and for human consumption. It has been shown that *S. serrata* gain weight faster and moult more frequently on diets containing higher protein (up to 55 percent of diet) and lipid (up to 15 percent of diet) levels. The same study demonstrated formulated feeds can produce feed conversion rations (FCR) of 1.2 to 2.1:1 for juvenile crabs. Related work also demonstrated that by increasing the protein content of mud crab feeds from 25 to 45 percent there was also a progressive increase in the protein content of crabs. From a feed formulation perspective, the levels of protein and lipid for incorporation would need to be based on economic outcomes, taking into account the cost of various formulations and the net value of the growth they support.

A range of plant and terrestrial animal-based ingredients can be efficiently digested by mud crabs, which have digestibility coefficients not significantly different from fishmeal. This ability to digest plant sources of carbohydrate is supported by work that demonstrated mud crabs have amylase and cellulase in their digestive system.

Practical formulated diets have been developed and tested for *S. paramamosain* and one with equal amounts of fishmeal and soybean performed optimally. For *S. paramamosain,* feeds high in protein and lipids are recommended; while for *S. serrata* good growth has been obtained on diets with 32–42 percent protein, 6–12 percent lipid and with dietary energy ranging from 14.7 to 17.6 MJ/kg. Other work has demonstrated that between 20 and 40 percent of fishmeal in mud crab diets can be replaced with soybean meal without affecting growth.

Differences in feed requirements between species of *Scylla* are to be expected, as is the case for different species of penaeid shrimp. An indication of this is that while the final weight of *S. serrata* increased as dietary lipid increased from 5 percent to 15 percent, for *S. paramamosain,* increasing lipid above 10 percent did not support further growth.

The physical attributes of formulated feeds have been found to be important when feeding mud crabs. When mud crabs have been grown on formulated shrimp feeds, it has been found that the largest shrimp pellet size available is too small for larger mud crabs, which is not surprising when considering the relative sizes of their respective mouthparts. In addition, it is noticeable that mud crabs are “messy” eaters when compared with shrimp, handling feed with their claws; so for crab feed wastage to be minimized, a good binder needs to be found. By examining the way mud crabs feed in the wild, for example when they consume marine worms, it has been suggested that mud crabs might feed more efficiently and effectively on tubular, “spaghetti-like” feeds.

Two other factors that will need to be addressed to improve the performance of formulated feed for crabs are their attractability and the likelihood that the feed for different-sized crabs will need to have different formulations, as is the case in shrimp feeds.

9.1.9 Feeding

Feeding rates utilized are often quoted as a percentage of the body weight of mud crabs in a pond (Table 9.2). As the quality and nutritive value of trash fish and other natural feeds varies significantly, these figures are difficult to generalize on.

Feeding frequency is typically once or twice a day, with feeding recommended every day to minimize the risk of cannibalism, which is considered more likely if the crabs are hungry. As mud crabs often seem most active late in the afternoon and early evening, one feed is commonly provided at that time.

9.1.10 Size at harvest

The size at harvest will depend on both the species being cultured and the needs of the markets that any particular farm is servicing. Most markets will take a variety of sizes but offer premium prices for particular types of mud crab. Premium prices can be obtained in most Asian mud crab markets for females carrying internal eggs, and for very large males with large claws.

TABLE 9.2
Feeding rates for *Scylla* spp. – wet weight using fresh diets (70–80 percent moisture)

Species	Daily feed provided as % body weight – on stocking	Daily feed provided as % body weight – towards end of crop	Reference
S. paramamosain	10–15	3–5	Thach, 2009
Scylla spp.	10	5	Baliao, De Los Santos & Franco, 1999
S. paramamosain	4–6	4–6	Dat, 1999
S. serrata, S. tranquebarica, S. olivacea	5–10	5–10	Quinitio, 2004

Note: Dry artificial diet feeding rates will be lower because of low moisture level.

Most markets have a minimum size below which it is difficult to market crabs. An example of this is Viet Nam, where a minimum size for mud crabs was 200 g while a premium price was obtained for crabs of 300 g.

9.1.11 Harvest techniques

While mud crabs are reasonably tolerant to a wide range of environmental variables, it is recommended that unnecessary stress be avoided during harvest. Wherever possible, avoid harvest activities during high temperatures, typically experienced during the day. In addition, preliminary grading at harvest should be undertaken as quickly as possible and unsuitable mud crabs returned to the pond to complete grow-out.

Once some of the crabs in a pond are identified as large enough to harvest, harvesting of crabs can commence. Crab pots of various designs can be used to harvest crabs. These are baited with food attractive to crabs. It is found that the largest crabs in a pond tend to enter traps first. As this is the case, ponds can be partially or selectively harvested on a regular basis, progressively removing the larger crabs from the pond.

To complete the harvest, either trapping is continued until no more crabs are trapped, or the pond is drain harvested, with crabs collected from the pond's drain or the lowest part of the pond.

As premium prices can be obtained for female "egg-crabs", females may be monitored and are only harvested when mature ovaries (red-orange) can be viewed through the carapace.

9.2 MANGROVE PENS

9.2.1 Preparation of mud crab pens prior to stocking

Prior to stocking with crablets, mud crab pens must be cleared of potential predators, large crabs and any unwanted species. If this basic precaution is not taken, crablets may simply end up as food and the farmer's investment in stock is wasted.

Farmer's need to use baited traps to remove all mud crabs from pens before restocking. Once a good number of baited traps have been set for several days in a pen and no crabs trapped, it can be considered free of mud crabs and ready for restocking.

9.2.2 Stocking

The size at which crablets are stocked into mangrove pens depends on the size of netting used and also if a nursery is installed within the pen. In the case of a pen with a nursery, small crablets of less than 1 cm CW can be stocked. Once the crablets are larger than 2 cm they can be released into the main pen.

The density at stocking that is used should produce 1–1.5 tonnes/ha. This figure needs to take into account typical mortality rates experienced, target production per hectare and the size of crab required at harvest.

The formula below can be used to calculate the number of crablets to stock in a mangrove pen:

$$x = a * h/b * 1/f$$

Where x = number of crablets to stock, a = area of mangrove pen (ha); h = final harvest weight required per ha (kg); b = average weight of crab at harvest (kg); f = farming mortality rate.

Example: If a = 2; h = 1 000 kg; b = 0.250 kg; f = 0.5
x = 2 * 1 000/0.250 * 0.5 = 16 000 crablets

While stocking from 5 000 to 10 000 crablets per hectare has been suggested as an appropriate stocking density for mud crab pens, higher densities may often result in higher mortality rates, so that the farmer spends more on crablets than is necessary. Survival rates from 20 to 86 percent have been reported from mud crabs stocked in mangrove pens in the Philippines at various initial sizes and stocking densities.

9.2.3 Feeding

It has been found that if a mangrove pen is stocked with wild-collected crablets, these can survive for one month without supplementary feed. However, if stock is from a hatchery and is used to being fed, supplementary feeding is required from the time of stocking.

If, while monitoring for food consumption using feed trays, it is found that all the food provided is not being consumed, the amount of feed per feeding event should be reduced.

Feeding is usually undertaken just before, or during an incoming tide, as this is when crabs emerge from their burrows in the mud to feed.

9.2.4 Feeds

Refer to 9.1.8.

9.2.5 Monitoring

Records should be kept on each mangrove pen to develop the best data set possible to assist the farmer to optimize production. No two mud crab pens will be exactly the same in terms of: the number of mangroves enclosed; drainage; natural productivity; tidal exposure; and sediment. The variability in production from mangrove pens is therefore, expected to be higher than from different ponds, which would be more similar in nature. This variability can be recorded, measured and used to a farmer's advantage.

It would be useful if farmers can keep basic records for each mud crab pen including:

- date crabs stocked;
- number of crablets stocked;
- average size of crablets stocked;
- supplementary feeds provided per day, including details of the type of feed used and the weight provided per feed;
- an estimate of feed used per day by comparing the percentage of feed left on feeding trays at the end of a feeding period;
- average size of crabs (every fortnight);
- any signs of disease; and
- number and mass of crabs harvested.

These records can then be used to calculate a number of key performance indicators for each pen, and for the farm as a whole, including:

- f = farming mortality rate = number of crabs harvested/number of crablets stocked.
- FCR = the ratio of gain in wet body weight of the crab to the weight of feed provided.
- growth rate.

9.2.6 Maintenance

The perimeter fencing of mud crab pens must be checked routinely to ensure that it has not been damaged or compromised in any way so that stock are able to escape.

As mud crabs are a relatively valuable commodity, farmers must be vigilant to prevent and minimize losses from poachers. Involving local communities in mud crab farming operations increases their ownership of such projects, which can result in community members assisting farmers in enforcing the security of their farms. Security is most important as stock is nearing harvest, as the mud crabs are then easier to catch and market. While some farmers construct shelters or buildings near their farm to enable them to monitor security, others may use random checks at different times of the day to act as a deterrent to thieves.

9.2.7 Harvest

Refer to 9.1.10.

9.3 CRAB FATTENING

The time it takes to fatten a mud crab for market depends on the degree of fullness of the crab when started on the fattening regime, its size (the larger the crab, the longer it will take to fatten), the temperature and feed provided. A crab fattening cycle typically takes from 14 to 60 days, during which time their protein content can increase from 8 to 15 percent. The fast turnover of stock, relatively low operating costs and high survival in crab fattening systems makes them economically attractive, assuming enough “empty” crabs are available, either from farms or wild harvest.

9.3.1 Assessing crabs – empty or full

To assess male and female crabs suitability for fattening, a simple guideline that has been developed in the Northern Territory, Australia, can be used. While the guideline will identify crabs suitable for fattening, it was developed and then included in legislation to minimize the take of “commercially unsuitable (“empty”) crabs”, so that such crabs are returned to the wild to fatten naturally. The introduction of this legislation has also resulted in Northern Territory mud crabs receiving premier prices as their fullness is almost guaranteed, compared with mud crabs from other locations that have more “empty” crabs included among their product. This test is considered 99 percent accurate, in that those mud crabs that flex have recently moulted, and as such would be unlikely to be full of meat (C. Calogeras, C-AID Consultants, personal communication).

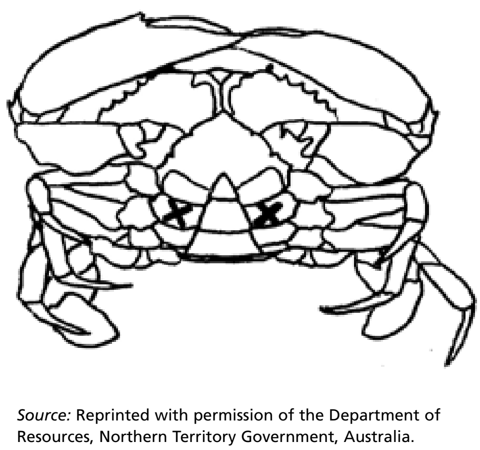
Figures 9.5 and 9.6 indicate how to identify an “empty” or “water” or “thin” mud crab.

To reduce cannibalism and damage to other crabs, crabs for fattening systems typically have their claws tied shut.

FIGURE 9.5
For a female mud crab – the carapace at both points shown in the diagram below is flexible enough to move inwards and make an audible sound when pressed if “empty”

Source: Reprinted with permission of the Department of Resources, Northern Territory Government, Australia.

FIGURE 9.6
For a male mud crab – both points shown in the diagram below can be pressed inwards if “empty”



Source: Reprinted with permission of the Department of Resources, Northern Territory Government, Australia.

9.3.2 Stocking

As crabs for fattening usually have their claws tied, they can be stocked at relatively high densities, e.g. 3–5 crabs/m^2. In some fattening systems, mud crabs are stocked in individual containers in cages or tanks to make assessing them simpler, the containers typically being designed to be just big enough for one market-size crab to fit.

9.3.3 Feeds and feeding in fattening systems

Mud crabs in fattening systems can be fed 7–10 percent of their total body weight per day, sometimes even higher (10–15 percent).

In fattening systems, mud crabs are typically fed trash fish or molluscs.

As fattening systems are also used to develop the ovaries of "egg crabs" for market, diets that have been developed to improve broodstock performance are also relevant. The diet in Table 9.3 achieved improved broodstock performance when fed in combination with natural feed compared with natural feed or broodstock diet alone.

TABLE 9.3
Composition of broodstock diet for the mud crab *Scylla serrata*

Ingredients	Percentage
Chilean fishmeal	20
Shrimp head meal	20
Squid meal	20
Wheat flour	17
Seaweed (*Gracilaria* sp.)	4
Cod liver oil	5
Lecithin	3
Cholesterol	1
Vitamin mix[a]	3
Mineral mix[a]	4
Dicalcium phosphate	3

[a] Vitamin and mineral mix, after Kanazawa (1981).
Source: Millamena and Bangcaya, 2001.

Approximate composition (%):

Crude protein	45.03
Crude fat	11.64
Crude fibre	5.18
Nitrogen-free extract	23.13
Ash	15.02

9.3.4 Harvest

When crabs are assessed as full (Refer to 9.3.1), they are removed from the fattening system, processed and packed (Refer to 10.9).

9.4 SILVICULTURE AND CANALS

9.4.1 Stocking and feeding

As no supplementary feed is provided to mud crabs in these systems, they are dependent on natural productivity. As such, stocking rates are typically very low (0.05 crabs/m^2).

Refer to 9.1.5 for details of assessing stock prior to stocking.

9.4.2 Harvest

Refer to 9.1.10.

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Part 10

Product quality

As most mud crabs are sold as a live product, it is essential that a quality control system is established that minimizes the risks of mortalities during transportation and ensures a quality product reaches the end consumer. Many companies are introducing Hazard Analysis and Critical Control Point (HACCP) programmes to underpin the quality of their processes and product. Some markets are moving to make the use of such programmes mandatory to protect their consumers. Country-of-origin labelling and health certification are two typical requirements.

It is recommended that an individual or company with professional experience in designing and operating a crab processing and packing facility be utilized to help design and setup any significant mud crab processing facilities, HACCP programmes and staff training. The costs associated with poor-quality product can be substantial, and make the difference between a business that succeeds or fails.

Each international market has different seafood safety standards and regulations that must be met, even before the product reaches the wholesaler or retailer. Facilities and operating procedures need to be developed to the appropriate standards to meet both government and traders' expectations, in the markets that the business intends to service.

Food-borne diseases caused by bacteria such as *Vibrio parahaemolyticus* have been linked to *S. serrata*, as well as other crustaceans. To avoid human health issues, it is critical that proper handling, storage and cooking practices are used throughout the supply chain and customers educated appropriately to ensure consistent quality of mud crabs.

10.1 POST-HARVEST

Once harvested from an aquaculture facility, mud crabs must be examined, cleaned and stored for transportation to a processing facility, unless this is situated on-farm. Recent work in Australia has highlighted improvements that can be made to enhance the post-harvest survival of mud crabs through a better understanding of their physiology and stresses that they are exposed to throughout the supply chain.

On harvest, farmers should tie the claws of mud crab crabs with string or vine to ensure that they cannot damage one another or people involved in further processing, distributing and selling the product (Figure 10.1).

To ensure that mud crabs intended for the live crab market are not "empty", "water" or "thin", crabs should be tested using the technique as detailed in Section 9.3.1. If found to be "empty", crabs should either be returned to the aquaculture facility or sent to a specific crab fattening facility should such be available.

FIGURE 10.1
Mud crabs with their claws tied

COURTESY OF COLIN SHELLEY

FIGURE 10.2
Preliminary packing of crabs in hessian sack to reduce desiccation

COURTESY OF COLIN SHELLEY

If crabs are to be transported to a temporary storage facility or processing shed, once taken from the water they are typically stored in a fish crate or container and covered with dampened material (e.g. hessian sack) (Figure 10.2) to reduce desiccation and protect against flies. Some preliminary sorting (by size, sex or missing limbs) may be undertaken at this stage depending on arrangements with the facility that will be doing the final processing and packaging. If mud crabs are to be held for some time before going to a processing facility, the containers holding the crabs should be kept in the shade and kept moist to avoid dehydration and heat stress. A spray system can be used to keep crabs moist, temperatures moderate and humidity high.

Post-harvest mortalities can be high (4–10 percent) if crabs are harvested in localities remote from markets and supply chains stress crabs significantly.

10.2 SIGNIFICANT STRESSORS OF MUD CRABS

When mud crabs are harvested, they are often kept out of water for considerable periods of time during which they are subject to a range of factors that stress them including:

- physical movement (handling, grading and transportation);
- exposure to breeze (resulting in enhanced dehydration);
- temperature, either too high, too low or sudden change;
- time, from harvest to processing, and from processing to market;
- respiratory metabolic stress, as they cannot obtain sufficient oxygen;
- starvation; and
- accumulation of ammonia.

The most useful biochemical indicators of stress in mud crabs have been identified as glucose and lactic acid within their haemolymph, and ammonia excretion (rather than ammonia in the haemolymph) when examined together.

10.3 HOW TO MINIMIZE STRESS IN MUD CRAB SUPPLY CHAINS

Various techniques can be used to minimize stress throughout the supply chain:

- Maintain crabs in a draught-free environment.
- Hold and transport crabs at as constant a temperature as possible, within the preferred range of 25–30 °C.
- Maintain crabs under a spray system to retain moisture and temperature.
- Dip or purge crabs in aerated water for 2 hours per day enabling them to excrete ammonia (3 hours following extended emersion).
- Utilize a recovery tank to hold mud crabs under optimal conditions for a period of time to regain condition prior to continuing along the supply chain.
- Cover or wrap mud crabs in damp-hessian-lined container to reduce moisture loss, avoid draughts and maintain temperature.
- Handle gently.

10.4 TREATMENT OF MUD CRABS IN PURGE OR RECOVERY TANKS

The most important intervention that can be made to reduce stress in mud crab supply chains is to immerse them in water, either as part of a short-term treatment, a purge, or being put into a recovery tank for a prolonged period of time. Such treatments have been shown to support vigorous, fully flavoured and fully weighted mud crabs reaching end users.

A 2- or 3-hour purge of mud crabs can be undertaken in relatively unsophisticated water tanks that can be flushed and refilled periodically to maintain good water quality, while removing ammonia, dirt and crab faeces. Freshwater or seawater can be used for short-term purging.

Recovery tanks for holding mud crabs for extended periods of time need to be based either on flow-through systems to maintain good water quality or on recirculation systems that continually filter the water to maintain suitable quality. Such systems should be of brackish water to full saltwater to minimize long-term stress on crabs.

Weight loss following emersion is rapid, with 2–3 percent being lost in the first hour and 4–8 percent in 24 hours. In addition to creating stress, this weight loss is also important to farmers and dealers as live crabs are sold by weight. However, such weight loss from emersion can be recovered within 2 hours if treated by immersion in a recovery or purge tank. Full recovery from an extended period of emersion, as measured using stress indicators, occurs within 24 hours.

If crabs have been kept out of water at high temperature (e.g. 30–35 °C) or for more than 7 days, purging time may need to be extended to 3 hours.

Recovery procedures can include purging in water tanks for 2 hours, which can either contain aerated fresh tap-water or seawater, as both support excretion of ammonia.

Care should be taken when putting mud crabs into recovery tanks, as if they have been immersed for several days, crabs can be momentarily stressed. If showing signs of difficulty, crabs can be pulled out for a few moments and then lowered back in until they appears vigorous in the tank and are not seen to be bubbling from the mouthparts. Moreover, crabs and water should be at the same temperature to minimize stress.

10.5 RECEIVING MUD CRABS INTO A PROCESSING FACILITY

All information highlighted in this section should be recorded on a standard form (receival), which forms a part of the overall quality control system.

When crabs first arrive at a processing facility, the internal temperatures of containers holding the crabs should be assessed before they are taken in. Crabs should be maintained at temperatures above 18 °C and below 30 °C to minimize stress. If temperatures within mud crab containers are outside this range, farmers or transporters need to be advised of the problem, and the crabs checked particularly carefully when processed.

On arrival, any containers that exhibit a bad smell, for whatever reason, should be rejected, as should any that exhibit crabs with maggots.

All received crab containers should be recorded and weighed, with the farmer or transporter obtaining a receipt. Containers from each farmer, pond or transporter can then be taken into the cool-room, and stored to maintain crabs in a low-stress environment.

Processing sheds or cool-rooms should already be set at the appropriate temperature to minimize crab stress. The processing area should be clean, tidy and organized ready to commence processing without delay. Once containers of crabs have been moved into the processing area, doors should be closed to maintain temperature and exclude flies or vermin.

As crabs are then processed, details of the receipt will be transferred to the grading, sorting or processing form, to ensure the traceability of product through the facility.

10.6 PROCESSING

Before grading commences, the cool-room or processing shed needs to be properly organized, with the appropriate items organized, which include crates (for different

TABLE 10.1
Preliminary grading of mud crabs

Grade	Description	Packed
Grades A, B, …	Lively/robust crabs	Yes
One claw	Lively/robust crab but missing a claw	Yes
Slow	Leg and antennae movement slow or weak	No
Commercially unsuitable crab (CUC)	Soft-shell, "empty", too old or unacceptable appearance	No
Discard	Dead or diseased	No

grades and rejects), packing tables, rubbish bins, weighing scales, pallets and forms. The facility should be setup according to the documented quality control system.

On arrival in a processing facility, crabs are usually rinsed to clean them prior to assessment by processing staff. Crabs from a particular farmer, pond or transporter are then selected for processing. Mud crabs from different suppliers to the processing shed must be handled separately, to ensure farmers are compensated accurately.

Table 10.1 provides an example of one system for grading crabs to meet a particular market's requirements. The grading system needs to be documented (checklists, posters on walls) and graders trained to be proficient in following it. All mud crabs should be handled with care to minimize stress and maximize product quality.

Any crabs that are untied must be retied before being graded. Untied crabs are a health and safety risk to staff. They can crawl around in transit, damaging other crabs and the box they are packed in, and also hurt freight handlers if crabs poke through damaged boxes or through the holes in boxes that are designed to allow air to circulate through them.

10.7 THE GRADES

10.7.1 Grades A, B, …

Top-quality, vigorous crabs with both claws intact and strong leg and antennae movement are the premium grade of hard-shell crabs for the live market. Often, this grade is further sorted by sex and size (e.g. small, medium and large). These grades would then be packed into separate boxes, if the market demands them to assist in marketing and also important if different prices are given to the different grades.

In addition, larger female grades may be further assessed to see if they are carrying ripe ovaries and can be classified as "egg crabs", another premium product. The status of a female crab's ovaries can be seen by holding it up to a strong light, the eggs being visible through the carapace.

FIGURE 10.3
Mud crab "bubbling" from around the mouthparts

COURTESY OF CCHRIS CALOGERAS

10.7.2 One claw

While a top-quality crab, from a health perspective, a one-clawed crab is not seen as a premium product in some markets, and will usually receive a lower price. As such, it is usually separately graded and packed.

10.7.3 Slow

A mud crab is deemed to be "slow" if its legs do not move when it is handled, or its legs brushed and will not walk if placed on a surface.

Included in the same grade are crabs that show "bubbles" (Figure 10.3) from around the mouthparts. Such crabs are likely to die in transit.

One death in a box can affect on the quality of other crabs in the same box, and may result in the box (usually 14+ kg) being rejected.

If available, slow crabs can be put into recovery tanks or ponds to see if they can regain condition and become of suitable quality for packing. Such facilities should be carefully monitored and mortalities removed as soon as possible. Otherwise, these crabs can be frozen, cooked or processed for meat.

10.7.4 Commercially unsuitable crabs

Commercially unsuitable crabs (CUCs) include soft-shell crabs that may have moulted on the way to the processing facility. If grow-out facilities are available nearby, such crabs could be returned for a further period of growth, or chilled or frozen immediately for the soft-shell crab market.

Crabs may be seen to be bleeding either transparent or bluish blood (haemolymph). As such crabs will die en route to the customer, they should be sent for freezing, cooking or killed for crabmeat production. In addition, bleeding crabs in a container may increase intercrab aggression.

If there are holes in any part of a crab's shell, the crab is not suitable for sale as the quality of its meat may be compromised.

Old crabs that may be covered with dark marks, or that have claws that are rather worn, may not be of acceptable appearance in some markets. These can be directed to lower-grade products for freezing, cooking or for crabmeat.

Some crabs will be of an unusual appearance, such as uneven claws. The acceptance or not of such crabs by buyers will determine how they should be graded and directed for further processing.

10.7.5 Dead or diseased

On no account should mud crabs that arrive at the processing facility either dead or diseased be utilized for human consumption. These should be sent to waste immediately. Bins containing dead crabs should be emptied from the processing area routinely and managed to prevent the buildup of smell, flies or vermin. Packing dead crabs in strong plastic bags is a good initial preventive measure. Removal of dead crabs from the processing site to a waste dump needs to be undertaken regularly.

10.8 FOOD HANDLING

Handling mud crabs is a critical stage in the supply chain. All employees involved need to be adequately trained in basic hygiene and food handling with regard to their personal responsibilities (e.g. washing, protective clothing, diseases). Procedures must be developed to minimize the risk of mud crabs being contaminated. These include ensuring that the product is:

- handled on surfaces that are clean and sanitized;
- protected from contamination;
- not exposed to disease (from staff);
- only handled by staff following rigorous and effective washing.

Detailed, site-specific procedures should be documented and regularly checked by supervisory staff.

10.9 PACKING

For local, domestic markets, mud crabs can be packed in plastic crates or containers of various descriptions. However, for export markets involving airfreight, wax-lined cardboard boxes, with ventilation holes at each end of the box, are commonly used (Figure 10.4). The design of such boxes has to be one approved for use by the airline companies. Of common use in Southeast Asia are boxes designed to hold approximately

FIGURE 10.4
Mud crabs packed in a wax-lined cardboard box for export

COURTESY OF COLIN SHELLEY

FIGURE 10.5
Mud crabs packed with head and claws tilted towards the top of the box

COURTESY OF COLIN SHELLEY

14 kg of crabs, packed in two layers. They are clearly marked with "up" arrows to indicate which way up they should be stacked.

Boxes used, the standard of processing facility, treatment of mud crabs prior to packing and their condition on arrival in a country may be defined by that country's export quality specifications. As such, there may be some variation as to how crabs are packed and managed for different markets.

As there can be many grades of mud crabs packed separately, boxes should be made up prior to a packing session commencing.

Staff should wear protective clothing and footwear that is easily washable, e.g. aprons and boots.

To assist in absorbing moisture, layers of paper are put in the bottom of the box, between the two layers of crab and on top of the crabs. Improved absorption can be achieved through the use of an absorbent pad or pads, made especially for such packing procedures, which are placed on the inner bottom of the box.

Crabs should be packed so that claws are not facing the outer edge of the box, with head and claws tilted towards the top of the box (Figure 10.5). This minimizes the risk of mud crabs becoming partially untied during transit and pushing their claws through box walls, potentially damaging freight handlers.

Each box should be clearly identified as to the grade of crab, the packer's number (to ensure the accountability of the packer), receival number (for traceability), date and total net weight of mud crabs packed.

Prior to shipment, boxes should be stacked neatly on pallets or similar. Boxes should not be stacked so high that lower boxes may be damaged by the weight of boxes and crabs above them. Four or five boxes high is usually acceptable for adequately constructed airfreight boxes.

At the end of a processing day, all equipment, floors and walls need to be appropriately cleaned, sanitized, tidied away and left to dry. The cool-room or processing shed should be closed when not in use in order to maintain temperature and keep out vermin or insects.

Gentle handling has been found not to create stress in mud crabs, so if daily sorting is necessary for crabs held in temporary holding facilities, this need not be avoided.

10.10 TRANSPORTATION

The best processing of mud crabs can be ruined by poor procedures and practices during the transportation process to market. The more steps there are in the transportation process, the more difficult it is to manage.

If packed mud crabs are exposed to very high or low temperatures, they can be stressed and even die, if exposed to temperatures outside their preferred range for too long. Sudden changes in temperature can stress mud crabs, causing significant fluctuations in soluble protein and sugars.

Temperature monitors can be packed in boxes that will measure temperature variation over time. Such information can assist in discussions with freight companies, airlines, wholesalers and retailers; identifying where in the supply chain temperature stress has occurred.

Other problems such as rough handling may be more difficult to identify, but the use of alternative freight companies or airlines, if available for particular destinations, may assist in defining where improvements need to be made and what interventions may be required.

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Part 11

Health management

11.1 BIOSECURITY

Compared with shrimp farming, knowledge regarding diseases of mud crabs and how to manage them effectively is still at an early stage of development. However, lessons learned from managing disease in shrimp farming can be adapted to mud crab farming, particularly in terms of developing a biosecurity programme for a farming enterprise.

The steps below are recommended for establishing a biosecurity strategy for a mud crab farm (adapted from the *Australian Prawn Farming Manual* [Anon, 2006]).

1. *Stock only crablets that have acceptable test results in terms of pathogen prevalence and load.*
   While currently few laboratories are experienced in assessing the disease status of batches of crablets, batch testing of crablets prior to stocking should become routine in the future. A range of diseases have already been identified in mud crabs, with tests developed for some of them already.
   A basic histo-pathological assessment of each batch of crablets to assess their health, prior to stocking, is recommended.

2. *Do not exceed optimal stocking densities.*
   While mud crabs are routinely stocked at low densities, stocking at high densities would stress them, as it does shrimp, making them more susceptible to disease. Stocking mud crabs at higher densities leads to more antagonistic behaviour, increasing the risk of cannibalism and damage to crabs, e.g. limb loss.

3. *Eliminate or reduce risk from potential vectors (infection carrying agents) on the farm.*
   While some living vectors such as birds or other animals can carry infected stock between ponds or pens, non-living vectors such as vehicles, nets, equipment and wastewater can also carry diseases. Appropriate disinfection of non-living vectors and restricting movement of vehicles around farms can reduce the risk, as can control of wild animals.

4. *Use water management practices that prevent or reduce contamination by any pathogen.*
   Particularly where farms occur at high densities and are in close proximity to one another, a precautionary approach to water quality needs to be taken. Minimal or even zero discharge of water, combined with the use of treated intake water, can reduce the risk of farm-to-farm contamination.

5. *Reduce the risk of spreading infection between ponds (or other farming units) by restricting movements of people, equipment and other possible agents.*
   This applies both to visitors to a farm, as well as farm staff. If staff are only involved in certain aspects of the farming operation, their movements should be restricted to only those areas they need to visit for their duties. If staff must move between different units of a farm, the use of facilities to wash hands and footwear between areas can be used to reduce the risk of transfer of disease.

6. *Implement a health management programme that aims to minimize stress to crabs by optimizing the pond (or other farming unit) environment.*
   Minimizing stress to mud crabs through optimal management of water quality and farming practices in general decreases the risk of infection.

11.2 MUD CRAB DISEASES

While some diseases such as white spot syndrome virus (WSSV) and Taura syndrome virus (TSV) often have little affect on mud crabs, they are known to be effective carriers and potentially viral reservoirs of these diseases. While the presence of WSSR in mud crabs can be assessed using polymerase chain reaction (PCR) testing, it has only rarely been reported that the virus can cause mortalities in them. In fact, the farming of mud crab in areas where shrimp farming has been devastated by WSSV has been recommended as an alternative farming opportunity.

A summary of diseases identified to date in mud crabs is listed in Table 11.1.

11.3 HEALTH MANAGEMENT

The development of a health management programme is a recommended strategy to minimize the risks of disease affecting any particular farm. Such a programme should be farm-specific and tailored to address key procedures and practices. A health management programme should address all key operational issues such as:

- pond or pen management;
- health monitoring;
- water quality management;
- feed management;
- husbandry practices;
- record-keeping;
- source of stock.

The source of stock has become a significant issue for international aquaculture. Stock of many aquaculture species has been translocated between countries and even continents, with some of these moves resulting in the transfer of diseases with that stock. The benefits of translocating stock need to be balanced against the risks involved. Importing stock should only be undertaken with appropriate safeguards, such as adequate health checking and quarantine procedures, in place to minimize the risk of introducing disease, as recommended in Article 9 of the Aquaculture Development section of the FAO Code of Conduct for Responsible Fisheries (the Code).

The four species of *Scylla* each have different geographic distributions, habitat and environment preferences. These should be seriously considered before any attempt is made to distribute them outside of their natural distribution, as inappropriate conditions for farming will lead to stress and increase the risk of disease.

11.4 DISEASE MANAGEMENT AND TREATMENT IN MUD CRAB FARMING

A limited number of treatments have been developed to assist mud crab farming operations. Much of the work in disease management has been directed to hatchery operations to improve mud crab larval survival, where the control of both bacterial and fungal infections has been critical. Improved pond management is the other area where substantial improvements can be made.

While prophylactic treatments, such as antibiotics for bacteria, or fungicides for fungi, have been used successfully to improve survival in mud crab larval systems, more progress has been made by the development of improved culture systems that reduce the risk of such infections in the first place.

The use of any chemical to treat a disease must be within government regulations controlling their use and under the supervision of trained staff.

In ponds, the use of quicklime as part of preparation prior to filling and stocking to disinfect ponds and reduce the incidence of disease has also led to improved survival, faster growth and more synchronous moulting of mud crabs.

A significant opportunity to reduce the incidence of disease on a farm is through strict control of sourcing broodstock and crablets. Avoid broodstock from areas known to have problems with parasites or disease. Already, attempts are being made to domesticate mud crab broodstock. Once this has been undertaken successfully, and stock with high health or disease-free status produced, stocking from this source, rather than wild broodstock or crablets, will further reduce the risk of disease on a farm.

TABLE 11.1
Diseases of mud crabs

Type/name/species	Description	Reference
Virus		
Baculovirus	No clinical disease	Anderson & Prior, 1992
Mud crab reovirus (MCRV)	Causes high mortalities, very pathogenic, PRC test developed	Weng *et al.*, 2007; Guo *et al.*, 2008
Mud crab muscle necrosis virus	White muscle, muscle necrosis	Song *et al.*, 2003
Unknown	Linked to mortalities in overwintered crab	Wang *et al.*, 1998
Bacteria		
Red sternum syndrome	Red legs, joints and discoloured haemolymph	Salaenoi *et al.*, 2006; Areekijseree, Chuen-Im & Panyarachun, 2009
Orange crab	Septicaemia, mortality, 5 species of bacteria (3 *Vibrio* spp.) found in haemolymph	Chong & Chao, 1986
Vibriosis	*V. harveyi* and *V. alginolyticus* caused vibriosis in larvae of *S. paramamosain*	Haryanti, Sugama & Nishijima, 2003
Yellow body disease	Unidentified bacteria isolated from *S. serrata*	Ji & Huang, 1998
Chitinoclastic bacteria	Bacteria led to damage of shells of mud crab broodstock over a 3-month period	Lavilla-Pitogo *et al.*, 2001
Diseased *S. serrata*, various symptoms	*Vibrio cincinnatiensis, V. alginolyticus, V. parahemolyticus* and *V. parahemolyticus* identified	Mao *et al.*, 2001
Non-identified bacteria	Bacteria caused mortalities in *S. paramamosain* larvae	Nghia *et al.*, 2007
Non-identified bacteria	Bacterial septicaemia, caused up to 60% mortality of *S. serrata* on east coast of China	Yang *et al.*, 1999
Fungi		
Order Lagenidiales	Fungal infection, ova and zoea	Bian *et al.*, 1979; Lio-Po *et al.*, 1980; Lio-Po *et al.*, 1982; Hamasaki & Hatai, 1993; Des, Takane, & Kishio, 1999
Haliphthoras	Fungal infection ova and larvae	Kaji *et al.*, 1991; Leano, 2002
Atkinsiella	From ova	Bian, 1980
Parasitic barnacles		
Sacculina granifera	Makes mud crabs unfit for human consumption	He *et al.*, 1992
Octolasmis spp.*, O. cor*	Infested crab gills, stalked barnacles can have debilitating effect, impacts on respiratory gas exchange	Sudakaran & Fernando, 1987; Jeffries, Voris & Yang, 1989; Jeffries, Voris & Poovachiranon, 1992; Safia & Javed, 2009
Parasitic dinoflagellate		
"Milky disease", "bitter crab disease" (BCD), "pink crab disease" (PCD), "yellow water disease" - *Hematodinium*	Acute disease in mud crabs. *Hematodinium* is one of the pathogens of "milky disease", which is similar to BCD and PCD. "Yellow disease" presents as white muscle and milky liquid in mud crab. The parasite is in the haemolymph and tissues. An indirect fluorescent antibody technique (IFAT) can detect *Hematodinium* in haemolymph of mud crabs	Xu *et al.*, 2007; Li *et al.*, 2008; Xie *et al.*, 2009
Other parasites and diseases		
Rust spot shell disease	Non-infectious, lesions and cavities in shell, up to 79% female, uncertain aetiology	Andersen, Norton & Levy, 2000
Loxothylacus ihlei, a rhizocephalan parasite	Prevalence ranges seasonally from 2–7% of *S. serrata*	Knuckey, Davie & Cannon, 1995

Some diseases, for example *Hematodinium*, appear to be related to the conditions under which crabs are kept. As optimal conditions for different *Scylla* spp. become better known, extreme conditions should be avoided, as they increase stress on stock and make them more susceptible to disease. Towards the edge of some mud crabs' distribution, this might mean that one rather than two crops a year may be produced, linked to favourable weather conditions. Alternatively, innovations can be developed to ameliorate conditions to support farms operating outside of ideal conditions, as has happened with overwintering of mud crabs in areas of China.

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The last decade has seen rapid expansion in the farming of several mud crab species in China, the Philippines and Viet Nam in particular. This manual is an introduction to all aspects of mud crab aquaculture. It provides a useful reference source for existing farmers, researchers and extension officers active in the industry and comprehensive baseline information for those in countries or companies interested in investing in this aquaculture sector.

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