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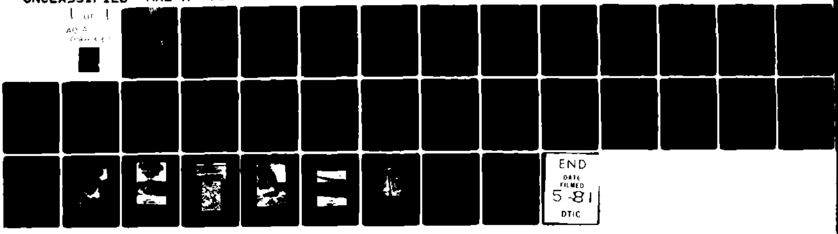

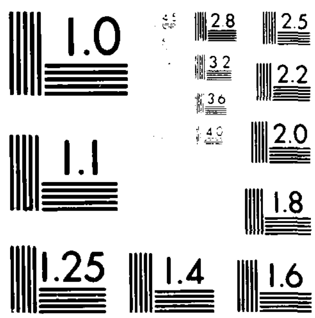

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MELBOURNE, VICTORIA

REPORT

MRL-R-795

THE EFFECTS OF UNDERWATER EXPLOSIONS ON MARINE LIFE IN SHOALWATER BAY, QUEENSLAND

I.C. Dunstan and J.A. Lewis

Approved for Public Release

SEPTEMBER, 1980

DEPARTMENT OF DEFENCE

MATERIALS RESEARCH LABORATORIES

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14) MRL-R-795

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(12) 34

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10 Ian C. Dunstan and John A. Lewis

ABSTRACT

A literature review is presented which details the available data on the effects of underwater explosions on marine life. This has been done at the request of Defence Facilities Division (Department of Defence) in order to assess the impact on marine communities of underwater explosions in Shoalwater Bay, Queensland. A general assessment of the possible effects of the explosions is given on the basis of overseas data relevant to the biological effects of underwater explosions, and from the limited data published on the marine communities of the Queensland coast.

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POSTAL ADDRESS: Chief Superintendent, Materials Research Laboratories
P.O. Box 50, Ascot Vale, Victoria 3032, Australia

DOCUMENT CONTROL DATA SHEET

Security classification of this page: UNCLASSIFIED

1. DOCUMENT NUMBERS:	2. SECURITY CLASSIFICATION:
a. AR Number: AR-002-378	a. Complete document: UNCLASSIFIED
b. Series & Number: REPORT MRL-R-795	b. Title in isolation: UNCLASSIFIED
c. Report Number: MRL-R-795	c. Abstract in isolation: UNCLASSIFIED

3. TITLE:

THE EFFECTS OF UNDERWATER EXPLOSIONS ON MARINE LIFE IN SHOALWATER BAY, QUEENSLAND

4. PERSONAL AUTHOR(S): DUNSTAN, Ian C. LEWIS, John A.	5. DOCUMENT DATE: SEPTEMBER, 1980 6. TYPE OF REPORT & PERIOD COVERED:
7. CORPORATE AUTHOR(S): Materials Research Laboratories	8. REFERENCE NUMBERS: a. Task: ALL 99/015 b. Sponsoring Agency: FASDF 9. COST CODE: 281580
10. IMPRINT (Publishing establishment) Materials Research Laboratories, P.O. Box 50, Ascot Vale, Vic. 3032 SEPTEMBER, 1980	11. COMPUTER PROGRAMME(S): (Title(s) and language(s)):

12. RELEASE LIMITATIONS (of the document):

Approved for Public Release

12-0. OVERSEAS: N.O. [ ] P.R. [1] A [ ] B [ ] C [ ] D [ ] E [ ]

13. ANNOUNCEMENT LIMITATIONS (of the information on this page):

No limitation

14. DESCRIPTORS:

630 Underwater Explosions Marine Biology
638 Shoalwater Bay Queensland Queensland
645 Fish Invertebrates Seagrass

15. COSATI CODES: 0603 0801

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(Continued)

THE EFFECTS OF UNDERWATER EXPLOSIONS ON MARINE LIFE IN SHOALWATER BAY, QUEENSLAND

1. INTRODUCTION

The Royal Australian Navy has proposed to establish an underwater demolition and mine disposal weapon training area at Townshend Island, Shoalwater Bay, Queensland (Fig. 1). In November 1977, Defence Facilities Division (Department of Defence) requested that Materials Research Laboratories conduct a literature survey to determine:

(i) the available quantitative data on effects of underwater explosions on marine life and ecosystems, and

(ii) the occurrence (or possible occurrence) of rare or endangered species of fish or other marine life, breeding grounds or other ecologically sensitive areas within Shoalwater Bay.

In addition it was requested that a short assessment be made of the effects that explosions of the proposed size and frequency would have on the marine life of Shoalwater Bay.

Three geographical regions were proposed for use in the training area at Townshend Island (Fig. 1). Areas 1 and 2 were proposed as mine disposal weapon training areas in which not more than 24 firings per year with a charge weight equivalent of 150 kg of TNT and 16 firings of 700 kg will occur. An underwater demolitions training area was proposed in area 3 (Triangular Island) where, each year, up to 240 firings of 10 kg over a 6 week period and 30 firings of 150 kg during a two week period will occur.

The underwater demolitions training area at Triangular Island was visited in July and November 1978. The initial survey was held concurrently with a diver training exercise by RAN Diving School HMAS PENGUIN and identified the regions in which explosives were detonated. Qualitative information on the structure of marine communities in these regions was collected which permitted the formulation of a sampling programme to quantify elements of the marine biota during the second visit to the area.

This report consists of two sections:-

(i) the results of the literature survey and an initial assessment of the possible effects of underwater explosions on marine life in Shoalwater Bay, and

(ii) preliminary observations on the composition of marine communities in the underwater demolitions training area at Triangular Island, with an appraisal of the effects of training activities on these communities.

A future report will detail the species composition, abundance and distribution of marine communities around Triangular Island.

2. A REVIEW OF THE LITERATURE ON THE EFFECTS OF UNDERWATER EXPLOSIONS ON MARINE LIFE WITH EMPHASIS ON SHOALWATER BAY, QUEENSLAND

2.1 Effects of Underwater Explosions on Marine Life and Ecosystems

2.1.1 Process of Damage

A marine community is a complex assemblage of organisms which inhabit a common environment and interact with each other, especially through food relationships. Primary producers, the photosynthetic plants, are grazed by herbivorous animals which become prey to carnivores. These carnivores, in turn, may be consumed by other predators. Scavengers and detrital feeders recycle nutrients into the food chain from dead organisms.

Underwater explosions may inflict damage on marine communities through two interrelated processes:

(i) the initial process of direct mortality to individual organisms in the immediate vicinity of a blast at the time of detonation, and

(ii) the secondary process which takes place as a consequence of direct mortality or physical disturbance from the explosion.

The secondary process may involve changes in the physical and/or vegetative structure of the region which may reduce the resident organisms' chances of survival [1]. Furthermore, an upset of the ecological balance within the food web, due to the selective mortality of susceptible species groups, may lead to food shortage through either removal of food items or increased feeding pressure from the hardier species in the absence of predators.

The inherent complexity of any marine ecosystem necessitates the examination of a wide spectrum of organisms which exhibit differing anatomical, physiological and ecological responses to an environmental stress before any understanding of the long term effects of this stress can be gained. The available literature relevant to the effects of underwater explosions on each major biological element of the marine community will therefore be discussed in following sections.

2.1.2 Effects on Macrobenthic Vegetation

Few studies on the biological impact of underwater explosions have quantified their effect on macrobenthic vegetation.

Ludwig [2] obtained data on the biological impact of explosives when used to kill off the seagress *Zostera marina* within the Niantic Estuary in Connecticut, USA. A channel through the dense stands of seagrass was required to re-establish a tidal eddy in the inner estuary. This eddy would then improve the level of dissolved oxygen and allow more complete habitation of the embayment.

Experimental detonations were performed with single and multiple charges and a weighted length of detonation cord. The size and type of charges were not specified.

The immediate physical impact of a single charge was a small crater 45 cm in diameter and 15-20 cm deep. Over an eight week period following the explosion, the seagrass exhibited orderly dieback along an expanding circle of defoliation to give a cleared area of 7-8 m diameter. Chain detonations created overlapping rings of impact which ultimately cleared a rectangle approximately 40 m long and 7-8 m wide, whilst the detonation cord created a similar impact but only 2-4 m wide.

Dieback of the seagrass was attributed to direct disruption of cellular structures within the rhizomes. Dieback was therefore restricted to the vascular seagrasses and did not affect the benthic algae.

An indirect effect of underwater explosions on benthic vegetation can be caused through disturbance of bottom sediments. Increased quantities of suspended sediment in the water column can reduce light penetration and photosynthesis, accelerate sediment deposition which smothers seagrass, change the redox potential within sediments and release toxins from the sediment [3]. Changes in redox potential of the sediments can make them unfit for recolonisation [4].

In a study of the temperate species *Thallassia testudinum*, it was found that the beds did not recover rapidly from physical disturbances such as boat traffic or dredging. This arose because the disturbed areas, whether sedimented in or scoured open, were not a suitable environment for rhizomal growth. Rhizomes require a full year to develop active new growth apices and do not grow rapidly [5]. The rate of recolonisation by tropical and sub-tropical seagrass species has not been studied in detail.

2.1.3 Effects on Invertebrate Species

a. Benthic Invertebrates

In the Niantic Estuary experiment (see above), soft-bodied invertebrates within close proximity of a blast crater suffered extensive mortality. Hard-shelled invertebrates were apparently unaffected by the blasts unless directly beneath or in extremely close proximity (*ca* 0.5 m) to the point of detonation. Recolonisation of devastated areas was well advanced within two weeks [2].

Controlled experiments have indicated that crabs and oysters are only affected when situated close to a blast site [6, 7].

Oysters suffered a 7% mortality when placed 30 m and 60 m from a 15 kg and 150 kg explosion respectively. Lobsters showed no sign of injury when 15 m from a 10 kg explosion [8]. Polychaetes, amphipods, isopods and sea anemones all showed greater resistance to underwater explosions than fish [7].

Coral boulders in close proximity to underwater explosions are destroyed [9]. Coral can also be damaged by the resettlement of disturbed sediments [10]. However, most corals can survive a constant rain of sediment from above unless this accumulates on the surrounding substratum and smothers them [11].

The removal of vegetation and disturbance to the underwater terrain can result in the exposure of resident invertebrates to increased environmental stress or predator pressure [12]. This occurred at Woods Hole, Massachusetts where seagrass beds died due to a Mycetozoan parasite and subsequent changes were noted in water circulation, dissolved oxygen content, temperature and pH of the water. The shelter and support afforded to invertebrates by the seagrass was also lost. 33% of the invertebrate species present before the removal of the seagrass disappeared [13]. Death of seagrass at Cape Ann, Massachusetts, also led to the disappearance of animal species characteristic of the community. However, the entire community subsequently reappeared with the re-establishment of the seagrass [14].

b. Planktonic Invertebrates

There is a lack of data on the effects of underwater explosions on marine zooplankton. However, increased pressure is reported to damage zooplankton species [15] and individuals in the vicinity of an underwater pressure pulse can sustain substantial damage. Such a loss of planktonic forms can reduce the food resources available to other species and place an unusual stress upon a community's food web [1].

2.1.4 Effects on Fish

a. Direct Physiological Damage

Information on the effect of underwater explosions has been obtained from controlled experiments [6, 7, 16, 17, 18, 19] and from *in situ* observations of the damage caused by underwater shock waves [2, 9, 20, 21, 22, 23]. All biota in close proximity to an explosion are usually killed. Fish with gas-filled swim bladders, which includes most commercial and game-fish species, are invariably killed over a greater range than other fish species [1, 16]. Biological damage to fish can be due to two causes [1]:

(i) changes in pressure over and under hydrostatic pressure, and

(ii) bulk cavitation.

Bulk cavitation occurs when the decompression pulse associated with the explosion is much greater than the hydrostatic pressure. The water will rupture, or cavitate, to produce an extensive region filled with bubbles of water vapour [6]. Since fish tissue and body fluids have similar physical properties to water [6] serious injury may occur in areas of bulk cavitation. Cavitation of fish body fluids creates an accumulation of gas bubbles which may result in embolism or inflict direct damage on blood vessels and organs [1].

Experiments which exposed caged fish to varying quantities of explosive have not produced a formula capable of predicting damage to either swim-bladder fish or other organisms [6, 7, 8, 25]. None of the simple explosive shock wave parameters of peak pressure, impulse or energy alone is a good criterion for the prediction of fish damage [6].

In one experiment, fish were caged at depths from 1.5 m to 30 m at a horizontal distance of 91 m from a 32 kg pentolite charge detonated at a depth of 9 m [7]. All *Trinectea maculatus* (hogchokkers), which do not possess swim bladders, survived whereas 85% of *Morone americana* (white perch) and 33% of *Ictalurus catus* (white catfish), which both have swim bladders, were killed. The lower mortality rate of *Ictalurus* is attributed to the thicker swim-bladder walls and greater body flexibility of this species compared with those of *Morone*; these properties reduced the incidence of swim-bladder rupture, internal haemorrhage and kidney bruising. Results do not enable quantitative prediction of fish kill as they are only representative of a particular experimental situation [7]. However, the susceptibility of fish species to underwater explosions may be inferred by comparative anatomical morphology with those species whose physiological response is known through controlled experiments [1].

Coker and Hollis [20] monitored the fish kill which followed twenty-one underwater explosions of 125-600 kg of HBX[2] (a high explosive, more powerful than TNT) in Chesapeake Bay, Maryland. The number and weight of fish killed were not proportional to the size of the charge exploded, but were attributed directly to the presence or absence of fish within the normal range of each blast. The lethal range, which was generally less than 200 m, would presumably depend on the size of the charge exploded. 32,658 dead or seriously injured fish were collected on the surface during these tests.

Hubbs *et al.* [2] found that there was a lethal range of 150 m from 12 kg explosions of nitro-carbonitrate for sardines and anchovies. The overall effect of this mortality on the fish populations in a region would depend on the number killed relative to the size of the surrounding population.

It should be mentioned that dead and injured fish collected on the surface after explosions do not represent the total mortality. Fitch and Young [24] observed that between 10% and 50% of fish killed are not visible from the surface. In other studies, only six of a total of sixty-six fish killed after demolition of coral boulders near Puerto Rico floated to the surface [9], and Young [8] observed fish to sink rather than float when killed close to an underwater blast.

Fish larvae would be adversely affected by underwater explosions as they are known to be sensitive to changes in hydrostatic pressure [25]. Mortality of fry and larval populations has been estimated to be substantial in the immediate vicinity of explosion sites [20]. High juvenile mortality could subsequently lead to a reduction in the size of adult populations.

b. Damage to Habitat

Fish stocks can be affected by damage inflicted on their habitat. Inshore vegetated areas function as important nursery and feeding grounds for fish species [26]. Damage to vegetation in these areas may remove important protective cover and increase the rate of predation on juvenile fish. The disappearance of invertebrate fauna associated with the vegetation could also lead to a decrease in the size of fish populations which depend on these species as food items [12, 13].

Destruction of seagrass beds in Boca Ciega Bay, Florida, resulted in an estimated loss of 1800 tonnes of infauna and 1100 tonnes of epifauna production per annum and a subsequent annual reduction of 73 tonnes in fisheries products [27].

2.1.5 Effects on Mammals and Birds

Experiments to determine the effect of underwater explosions on marine mammals and seabirds demonstrated that birds on the surface were not injured unless in the immediate proximity of an explosion which, in one instance, was within 6 m of a 4 kg TNT charge exploded at a depth of 3 m [28]. Injury was minimal as the kidneys and other vulnerable organs of floating birds lie above the water surface. Submerged mammals and birds may sustain a variety of damage ranging from ear-drum rupture and lung haemorrhage to mortality. The actual damage inflicted depends on the magnitude of the impulse received. For submerged birds and mammals, 20 m was considered a safe distance from a ½ kg charge detonated at a depth of 3 m [28].

2.2 Marine Biological Communities of the Shoalwater Bay Region

2.2.1 Vegetation

The shallow waters of Shoalwater Bay are reported to support extensive areas of seagrass [29]. However, this is the only reference to the subtidal marine vegetation of the region. Mangroves are common in sheltered coastal areas of the bay (Fig. 1) [30].

Seagrass beds are found in shallow, protected bays and channels along the Queensland coast [3]. The ecology of seagrass communities in these areas is poorly understood, with no studies currently being undertaken north of latitude 25°S [31]. Den Hartog [32] reports 5 prominent species of seagrass from inshore Queensland waters: *Syringodium isoetifolium*, *Halodule uninervis*, *Halophila spinulosa*, *Cymodocea rotundata* and *Zostera capricorni*.

A study of seagrass communities in Moreton Bay is being undertaken by the CSIRO Division of Fisheries and Oceanography in connection with work on prawn fisheries [26, 33]. Six species of seagrass, *Zostera capricorni*, *Halodule uninervis*, *Halophila ovalis*, *Halophila spinulosa*, *Cymodocea serrulata* and *Syringodium isoetifolium*, were found in five distinct phanerogamic communities. The zonation of the communities were related to depth, salinity, turbidity and substrate characteristics [33]. Similar communities have been recorded from Tin Can Inlet and Great Sandy Strait [34].

Ecological studies of the marine algae along the Queensland coast are confined to the offshore islands [35, 36] and observations cannot be related to the Shoalwater Bay region.

2.2.2 Invertebrates

As part of an extensive survey of intertidal organisms along the rocky shores of the Queensland mainland, surveys have been performed at Yeppoon to the south, and Shoal Point to the north of Shoalwater Bay [37]. Organisms at these sites were typical in composition and zonation with those recorded on rocky coasts from Double Island Point (26^{o}S lat.) northward to Cairns (17^{o}S lat.). This assemblage of species would therefore be expected to occur on rocky shores in the Shoalwater Bay area.

No surveys of the subtidal biotic communities have been undertaken in areas near Shoalwater Bay. However, the macrobenthic fauna of Moreton Bay in southern Queensland has been surveyed [38, 39, 40, 41, 42]. Different regions within Moreton Bay were found to vary considerably in the identity and abundance of macrofaunal species. Because of this variation, detailed survey results cannot be applied to other embayments on the Queensland coast, such as Shoalwater Bay, although they provide a general guide to the expected composition of species.

Similarly, epibenthic faunal species listed from soft substrates in the littoral and infralittoral fringe of Moreton Bay [43] may occur on similar substrates in Shoalwater Bay.

Small patches of coral exist near the mouth of Shoalwater Bay [44] but coral growths are not frequently encountered along the northern Queensland mainland despite the abundance of offshore reefs [37]. The paucity of coral growth is attributed to the fluctuations in salinity experienced in inshore waters.

Seagrass communities in Queensland have been found to be important nursery areas for penaeid prawns [26] and would presumably assume this function in Shoalwater Bay. Commercial prawns spawn in the ocean. When the juveniles are about 1 cm long they float into bays and settle around shallow sandbanks and mudflats. As they grow, they move into deeper parts of the bay and then out to sea where the life cycle continues [45]. Major commercial prawn production areas in Queensland are consequently associated with extensive regions of shallow water, such as found in Morton and Harvey Bays.

As Shoalwater Bay contains extensive areas of seagrass [29] the bay probably supports a large prawn population. Prawn fisheries, which may depend on the Shoalwater Bay region as a nursery ground, form a major proportion of the intake at the nearby Rosslyn Bay and Yeppoon fish markets [46].

2.2.3 Fish

Commercial fishing in the Shoalwater Bay region, as indicated by the intake at the Yeppoon Fish Market [46], accounts for 11% of barramundi, 16% of cod, 36% of kingfish, 12% of jewfish, 11% of trevally and 16% of the salmon caught in Queensland waters. Of these species, barramundi, jew, king and salmon are dependent on shallow bays and inlets at some stage of their life cycle [34]. The shallow waters of Moreton Bay in southern Queensland have been found to support over 250 fish species which include both permanent resident species and the juvenile stages of commercially important deep-water species [45].

The estuary of Shoalwater Creek, at the southern end of Shoalwater Bay, is noted for its fishing [29]. The prominent species include barramundi (*Lates calcarifer*), threadfin salmon (*Polydactylus sheridani*) and sea mullet (*Mugil cephalus*). No other references to the marine fish in Shoalwater Bay have been found.

2.2.4 Reptiles

The saltwater crocodile (*Crocodilus porosus*) occurs in estuarine and mangrove areas of Shoalwater Bay and four species of marine turtle have been recorded in adjacent waters [29]. These marine turtles are known to feed on seagrass in shallow inshore regions [3, 26, 45].

2.2.5 Birds

The white-necked heron (*Ardea pacifica*) and white-faced heron (*Ardea novaehollandiae*) are common throughout the Shoalwater Bay Region where they forage on the exposed mud flats. Pied cormorants (*Phalocrocorax varius*) and pelicans (*Pelicanus conspicillatus*) are also numerous in both marine and estuarine habitats [29]. Reef herons (*Egretta sacra*) have been observed at several points along the coastline.

2.2.6 Mammals

A population of dugongs, or sea cows, (*Dugong dugon*) is reported to inhabit the extensive shallow-water seagrass communities of Broad Sound and Shoalwater Bay [29]. Dugongs are reputedly plentiful in these waters with herds of up to a dozen animals. This population is relatively undisturbed by man due to the recent gazetting of the Shoalwater Bay Military Training area which has excluded all fishing activity [47]. The number, distribution and activity of dugongs in Shoalwater Bay were assessed by aerial survey on three days during 1975 [48]; these survey flights traversed areas thought to be favourable to seagrass growth and, therefore, likely dugong feeding grounds. The Triangular Island region was covered in two of the flights but dugongs were only observed along the mainland coast (Fig. 2). Detailed studies of dugong behaviour were subsequently concentrated in the Ross Creek region where most dugongs were sighted.

The dugong, which is the only herbivorous mammal species that is strictly marine, is distributed along the sub-tropical and tropical coasts of the Indian and Western Pacific Oceans. Except when in transit, dugongs stay close to their food supply in those shallow coastal waters where the bottom is of a suitable grade of silt or sand to support vigorous growth of higher green plants [47]. Dugongs feed preferentially on seven species of seagrass in intertidal and subtidal regions to 9.5 m below low water datum [3, 49]. They apparently graze most heavily on seagrass beds of low density and their general movements and feeding habits are largely dependent on tides and weather. Dugongs are only observed in unsheltered coastal waters in calm weather [3].

The reported Australian distribution of dugongs encompasses the northern coastline from Moreton Bay (20^{o}S lat.) in the east to Shark Bay (20^{o}S lat.) in the west [3]. The dugong is considered rare, or in danger of extinction, over most of its range [47, 50, 51], although sizeable populations have recently been reported in northern Australia [3, 47, 52, 53]. It is a legally protected species in Queensland, the Northern Territory and Western Australia [3].

Little is known about the seasonal movements of dugongs but observations suggest some may be nomadic or migratory, whilst others remain resident in a given area [3]. Heinsohn and Wake [54] propose that if dugongs do undergo extensive migrations, then each large, shallow, protected bay along the Queensland coast, - Shoalwater Bay, Moreton Bay, Upstart Bay and Cleveland Bay - would be of importance to the survival of the species. Accordingly, these bays should be considered as critical to the well being of the species because there are long stretches of the Queensland coast that are obviously unsuitable as dugong habitats. A dugong tagging program, in conjunction with continued aerial surveys, is being developed in northern Queensland to determine the extent and nature of dugong movements [3].

2.3 Possible Effects of Underwater Explosions on Marine Life in Shoalwater Bay

2.3.1 Destruction of Seagrass Beds

Underwater explosions are known to kill areas of seagrass (Section 2.1.2), and seagrass beds are found on shallow mudbanks in Shoalwater Bay. The severity of damage to these beds would depend on the siting of the blasts, on the magnitude of the blast and accompanying shock wave, and on the long-term rates of seagrass recolonisation. Of the three test sites (Fig. 1), conditions for seagrass growth would only be met in the shallow waters around Triangular Island. The test site near Raynham Island, off the outer coast of Townshend Island, would presumably be too deep and too exposed to wave action for seagrasses whilst the test site off Leicester Island is also in deep water and therefore unlikely to support prolific seagrass growth.

The destruction of seagrass beds by underwater explosions would lead to the disappearance of faunal communities which depend on seagrass habitats (Section 2.1.3). Although few species feed directly on seagrass, the notable exceptions in tropical Queensland being marine turtles and dugongs, the seagrass beds function as important nursery grounds for juvenile fish and prawns. This is primarily due to the protection afforded by the beds themselves and to the high availability of food provided by the rapid recycling of nutrients as seagrass decomposes. Damage to seagrass beds can also lead to substrate erosion as the beds form an important function in stabilising the sediments.

2.3.2 Invertebrate Kill

The effects of direct kill on invertebrate species, both benthic and planktonic, would depend on the number of individuals killed relative to the total population size, and the effect of explosions on their habitat. If habitat disturbance is minimal, and only a small area is affected by each explosion, then the invertebrates killed would be rapidly replaced from surrounding populations. The rate of recovery of the invertebrate populations would be indirectly proportional to the area affected. If the habitat is seriously disturbed, however, recolonisation would not commence until after the habitat recovered.

Corals which grow in the region of test sites would be unlikely to incur damage from the deposition of silt associated with underwater explosions. Winds inside the Great Barrier Reef create sufficient water turbulence to suspend fine sediments and result in high water turbidity along the mainland coast [55]. Animals found commonly on the mainland shores of Queensland are able to tolerate this turbidity and associated build up of silt [37].

2.3.3 Fish Kill

Fish in the immediate vicinity of underwater explosions will be killed. The overall effect on fish populations will depend, however, on the number killed relative to the size of surrounding populations (Section 2.1.4) If the latter populations are large, the long-term effects of fish mortality would be minimal as individuals would be present to recolonise disturbed areas.

On the basis of available literature (Section 2.1.4) fish with swim bladders are likely to be killed, or suffer serious injury, within 300 m of the proposed 750 kg firings. No data are presently available on the density or composition of fish species in Shoalwater Bay and the size of fish kill cannot therefore be estimated.

Coker and Hollis [20] suggested that care must be used in the planning of tests to select times when fish are absent from the test site. In estuarine waters this may prove difficult because many species are involved and the times of feeding and of spawning migrations will vary between species.

2.3.4 Other Animals

No data are available on the effects of underwater explosions on marine mammals. However, it can reasonably be assumed that individual animals would be killed, or injured, within the immediate vicinity of the blasts. Mortality to dugongs would therefore depend on their feeding habits and distribution within the Shoalwater Bay region. Dugongs are reported to have a strong aversion to noise [47] and the sound of explosions may disrupt their normal behaviour patters within Shoalwater Bay. Damage to seagrass beds may also lead to changes in the regular feeding habits and distribution of individual dugongs, as happened following the destruction of seagrasses by Cyclone Althea near Townsville [53] in 1973.

The apparent absence of dugongs near the test areas (Section 2.2.6) would eliminate the possibility of interference to their populations in Shoalwater Bay. Furthermore, the dugong's aversion to noise may serve to deter them from entering the test areas during training activities.

Turtles, pelicans, herons and cormorants may be killed if in the immediate vicinity of explosions.

3. THE EFFECTS OF UNDERWATER EXPLOSIONS ON MARINE COMMUNITIES AROUND TRIANGULAR ISLAND

3.1 Marine Communities in the Triangular Island Training Area

Triangular Island consists of two low, wooded islets which are connected by a narrow spit of rocks that is barely covered by water at low tide. The shores of these islands are composed of sand or rock and slope gradually into the waters of Shoalwater Bay. Due to the large tidal rise in the bay (> 6 m), extensive intertidal mudflats surround the islets and extend for up to 600 m from the high-water mark (Fig. 3; Plate 1). Mangrove stands grow on sheltered regions of mudflat at upper-tide levels (Fig. 3).

The following observations on the composition of marine communities in the area were made during visits to the region by MRL staff.

Few macroscopic marine plant species are able to grow on mudflats due to the lack of firm substrata for attachment and the rigours of repeated exposure to the atmosphere. Around Triangular Island, the seagrass *Zostera capricorni* Ashers is the dominant plant species on the mudflats (Fig. 3; Plate 2). A second seagrass species, *Halophila ovalis* (R. Brown) Hooker f., is also found but in low abundance. Algal species are mostly diminutive and, with the exception of two species, only grow on shells or pebbles in small pools on the mud. The exceptions are the blue-green alga *Lyngbya majuscula* (Dillwyn) Harvey and, to a lesser extent, the green alga *Enteromorpha clathrata* (Roth) Greville whose filamentous habits enables them to form thin mats on the mud surface. A more diverse algal flora exists in the shallow continuously submerged waters beyond the mudflats and in the few large pools within the intertidal zone.

The mudflats support a prolific community of invertebrate species which are capable of burrowing into the mud. Such species include crabs, worms and molluscs and their presence is made obvious by the abundance of open burrows and worm faeces across the mud surface (Plate 3a). The composition of the community which inhabits the mud will be detailed in a future report. Numerous small hermit and soldier crabs are seen on the surface of the mud at low tide. Hard and soft corals are confined to the large, sandy pools between the two islets (Plate 3b) and to the shallow waters beyond the mud-flats. The oyster *Crassostrea amasa* (Iredale) carpets rocky surfaces in the upper intertidal zone.

With the exception of the mud-skipper *Periophthalmodon koelreuteri* (Pallas), fish are unable to survive exposure on the mudflats and therefore move into deeper water as the tide ebbs. With the flood tide, they return to feed on the large, resident populations of invertebrates. A list of fish species collected in the Triangular Island area is given in Table 1. The eastern king prawn *Penaeus plebejus* Hesse has also been found in waters over the mudflats. A future report will detail the size, distribution and abundance of fish species taken by net hauls over the mudflats.

Green turtles, *Chelonia mydas* (Linnaeus), are plentiful in the waters of Shoalwater Bay. These were frequently observed stranded in the pools and on the mudflats along the western side of the island at low tide.

No dugongs were sighted in the Triangular Island region and there was no evidence of dugong feeding activity on any of the seagrass beds around the island. If dugongs did frequent this region, feeding trails would be expected through the beds.

3.2 Underwater Demolitions Training at Triangular Island

The majority of explosions detonated during diver training exercises at Triangular Island are situated at either 'Little Bag' or 'Big Bang' Beaches and are almost exclusively in the intertidal zone (Fig. 3; Plates 1, 4). At each site, an area of approximately 1 ha is used which extends seaward from the high-water mark. Substratum in the affected area of 'Little Bang' Beach is mud whilst that of 'Big Bang' Beach is a mixture of mud and shingle.

The actual positions of explosions are readily seen on 'Little Bang' Beach (Plate 1b) because the craters in the mud persist for considerable periods. No appreciable reduction was observed in the size of the craters over the four months between the two MRL visits to Shoalwater Bay. Smaller disturbances of the mud surfaces, such as footprints (Plate 5), also appear to persist for a considerable time.

The physical effects of small explosions on 'Big Bang' Beach were much less marked than at 'Little Bang' Beach. Several large charges have been used on 'Big Bang' Beach to blast a channel to the beach for the use of small craft (Plate 4b) but smaller charges do not greatly disturb the substratum. On 'Little Bang' Beach, however, the finer sediments are more easily disturbed and have a viscid consistency which retards subsidence of the crater walls.

Occasional blasts are also detonated at sites offshore from the island (eg. Fig. 3, point C) but these are subtidal and the effects could not be ascertained.

3.3 Effects of Diver-Training Exercises on Marine Life at Triangular Island

Underwater explosions cause considerable, persistent disturbance to mudflats in the direct vicinity of blasts. In the Triangular Island region, however, the area disturbed is small when compared to the total area of mudflats around the island and in Shoalwater Bay as a whole. In addition, the areas presently used are devoid of seagrass and the important biological communities often associated with seagrass beds (Section 2.1.3) are therefore unaffected by training activities. This would not be the case if explosives were used in other regions of mudflat around the island where extensive seagrass beds do occur. The lack of seagrass in the training areas does not appear to result from diver-training activities but is a general feature of the two regions where explosives are used.

The populations of invertebrates which inhabit the mudflats appear unaffected by the explosions. For example, crabs adjacent to an exploding detonator cord at low tide (Plate 5) were blown out of their burrows but only those in the direct path of the explosive were damaged. Similarly, invertebrate populations in the crater area of a larger explosion would incur high mortality but these areas would be rapidly recolonised from surrounding populations (Plate 3a).

The size of fish kill depends on the number of fish present in the immediate vicinity at the time of the explosion. Although killed over a wider area around the blast than invertebrates (Section 2.1.4), the numbers affected would still be small compared to the total numbers present over the mudflats in the Triangular Island region at any time. In the long term, fish numbers would not be markedly affected at either 'Little Bang' or 'Big Bang' Beaches as fish do not permanently inhabit specific regions of mudflat but migrate with each incoming tide.

The species and numbers of fish killed by two explosions in the test area are listed in Table 2. The size of the kill may not be accurate as only those fish which floated or were washed ashore are included. Fitch and Young [24] proposed that between 10% and 50% of the total numbers of fish killed by an explosion would not be visible from the surface. The maximum kill expected from the 1200 lb blast would therefore be 16 fish.

Several species of fish move across the submerged mudflats in schools and these can cause a higher fish kill if they are in the vicinity of a blast. Such a kill of garfish was reported from a blast in the week prior to MRL's visit to Shoalwater Bay. However, even this type of kill would have less effect on populations than that of a single haul by a fisherman with a beach seine net. As Shoalwater Bay is a restricted area, it is important to note that the area is not subject to the commercial fishing pressures experienced by other estuaries and embayments along the Queensland coast.

Seabirds and turtles are unlikely to incur any mortality or injury as neither have been observed in the test areas during periods of activity. A likelihood exists, however, that one of these animals may at some time be caught in the vicinity of a blast, but the possibility is considered to be low. Dugongs are not known to frequent the Triangular Island region and are therefore unaffected.

4. CONCLUSIONS

4.1 Possible Effects of Underwater Explosions on Marine Life in Shoalwater Bay

a. An extensive literature search failed to detect any reports on the effects of underwater explosions on Australian marine life. Literature from overseas sources indicates that all organisms within close proximity of an explosion would be killed. No information is available to enable the kill distance of organisms from an explosion of known type and size to be determined.

b. Underwater explosions are known to kill areas of seagrass and lead to removal of their associated, ecologically-important fauna.

c. Invertebrate species, including prawns, would only be killed in the immediate vicinity of explosions. The overall effect on populations would depend on the size of surrounding populations and the extent of habitat damage.

d. The number of fish killed by an explosion depends on the absolute number of each species present in the kill zone at the time of detonation. However, the overall effect on fish populations in a region will depend on the number killed relative to the size of the surrounding population. Fish with gas-filled swim bladders are killed at much greater distances than other fish species or marine invertebrates.

e. The endangered dugong exists in Shoalwater Bay but populations are not known to frequent areas selected as test sites.

4.2 Effects of Underwater Demolition Training on Marine Life Around Triangular Island

a. Underwater demolition training activities are confined to an area of intertidal mudflats small in relation to the total area of mudflats that surround Triangular Island. The Triangular Island mudflats are, in turn, small when compared to the total area of mudflats in Shoalwater Bay.

b. The present test areas are in regions naturally devoid of seagrasses, although seagrass beds do occur around Triangular Island.

c. Invertebrate and fish kill, by explosions of the currently-used magnitude and frequency, are small in comparison to population sizes in the region and would not adversely affect community structure. The infrequency of training activities would allow time for invertebrate species to recolonise disturbed substrata. As Shoalwater Bay is a restricted area, fish populations are not subjected to the additional pressure of commercial fisheries.

5. ACKNOWLEDGEMENTS

We wish to acknowledge the cooperation of the Commanding Officers and crew of HMAS BALIKPAPAN and divers from Clearance Diving Team One and Diving School HMAS PENGUIN whose cooperation and assistance enabled the visits to Triangular Island to be successful. Appreciation is also extended to Mr J.R. Forsyth of MRL who assisted on visits to Shoalwater Bay.

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T A B L E 1

LIST OF FISH SPECIES COLLECTED IN WATERS ADJACENT TO TRIANGULAR ISLAND, SHOALWATER BAY

Scientific Name	Common Name
Rhinobatos sp.	Shovel-nose Ray
Engraulidae sp.	Anchovy
Harengula koningsbergeri (Weber & de Beaufort)	Spotted Herring
Arrhamphus sclerolepis Gunther	Snub-nose Garfish
Hyporhamphus ardelio (Whitley)	River Garfish
Liza vaigiensis (Quoy & Gaimard)	Diamond-scale Mullet
Mugil georgii Ogilby	Fantail Mullet
Pranesus ogilbyi Whitley	Common Hardyhead
Absalom radiatus (Macleay)	Fringe-finned Trevally
Trachinotus blochi (Lacepede)	Snub-nosed Dart
Priopidichthys marianus (Gunther)	Yellow Perchlet
Therapon jarbua (Forskal)	Crescent Bass
Acanthopagrus australis (Gunther)	Bream
Gerres argyreus (Bloch & Schneider)	Darnley Island Silverbelly
G. filamentosus Cuvier & Valenciennes	Spotted Silver-biddy
Sillago maculata Quoy & Gaimard	Trumpeter Whiting
Monodactylus argenteus (Linnaeus)	Silver Batfish
Selenotoca multifasciata (Richardson)	Butter Fish
Siganus sp.	Spinefoot
Periophthalmodon koelreuteri (Pallas)	Mud-skipper
Platycephalus indicus (Linnaeus)	Bar-tailed Flathead
Tripodicthys angustifrons (Hollard)	Tripod-fish
Spheroides hamiltoni (Gray & Richardson)	Common Toado
S. pleurostictus (Gunther)	Banded Toado
Arothron immaculatus (Bloch & Schneider)	Narrow-lined Toadfish

TABLE 2

FISH KILL FROM TWO EXPLOSIONS ON 'BIG BANG' BEACH
TRIANGULAR ISLAND

Size of Explosion (lb)	Fish Species	No Killed	Aver. Length (cm)
20	*Acanthopagrus australis*	2	16.9
	Absalom radiatus	1	16.0
1200	*Acanthopagrus australis*	1	19.0
	Absalom radiatus	2	18.2
	Gerres filamentosus	3	15.0
	Gerres argyreus	1	15.2
	Sillago maculata	1	20.0

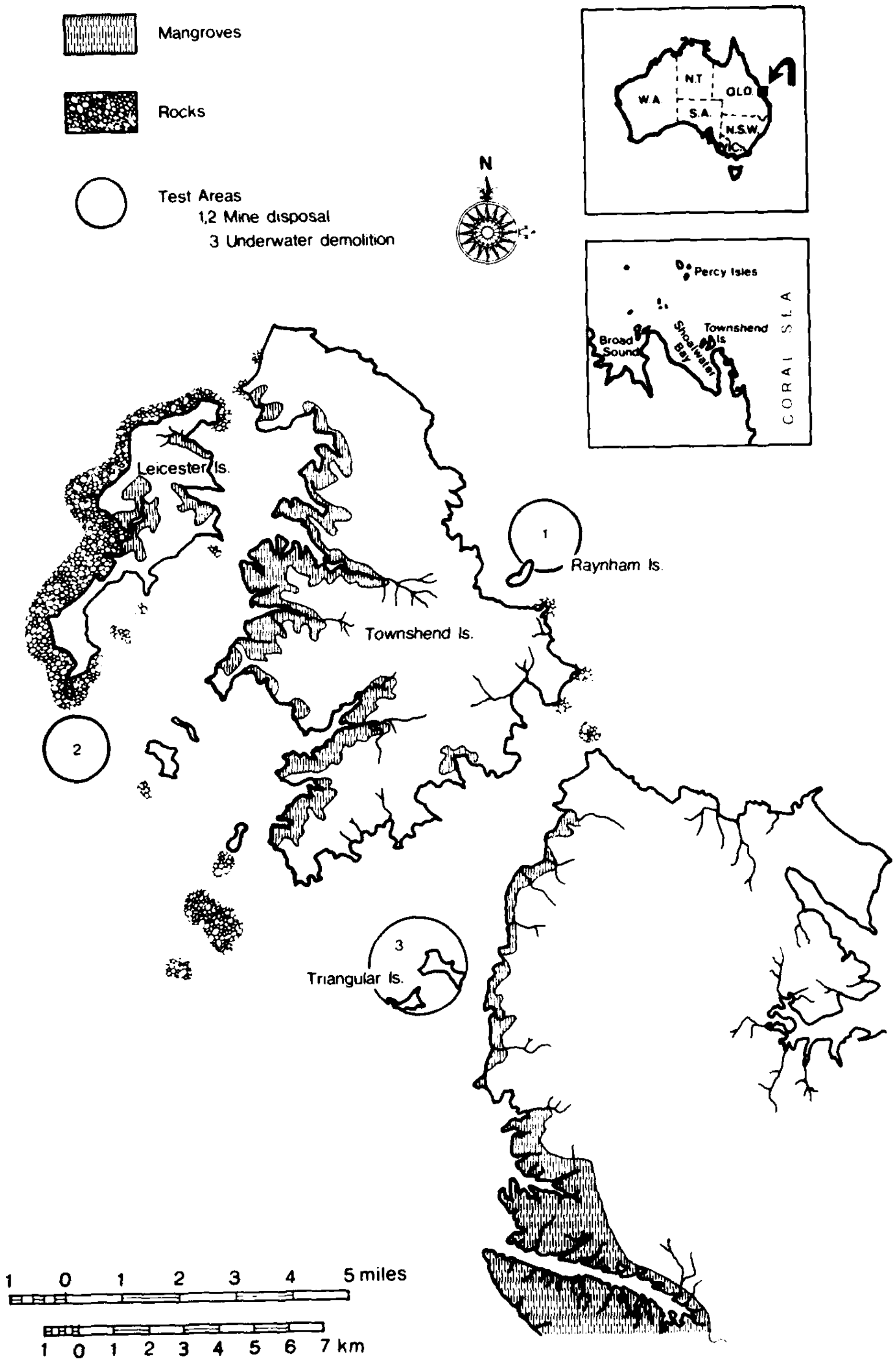


FIG. 1 - Map showing the locality of Shoalwater Bay and sites selected for underwater explosions

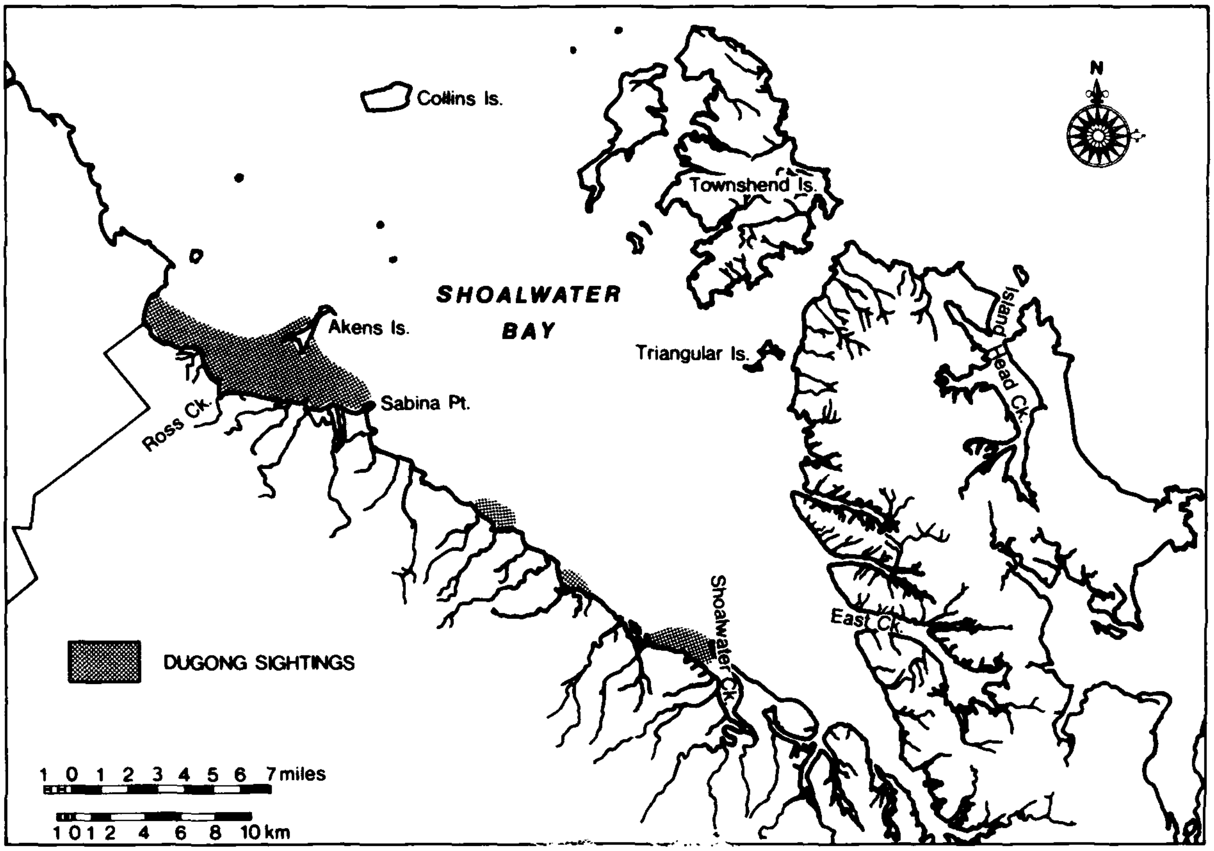


FIG. 2 - Areas of Shoalwater Bay where dugongs were sighted in the aerial surveys of Anderson and Birtles (1978).

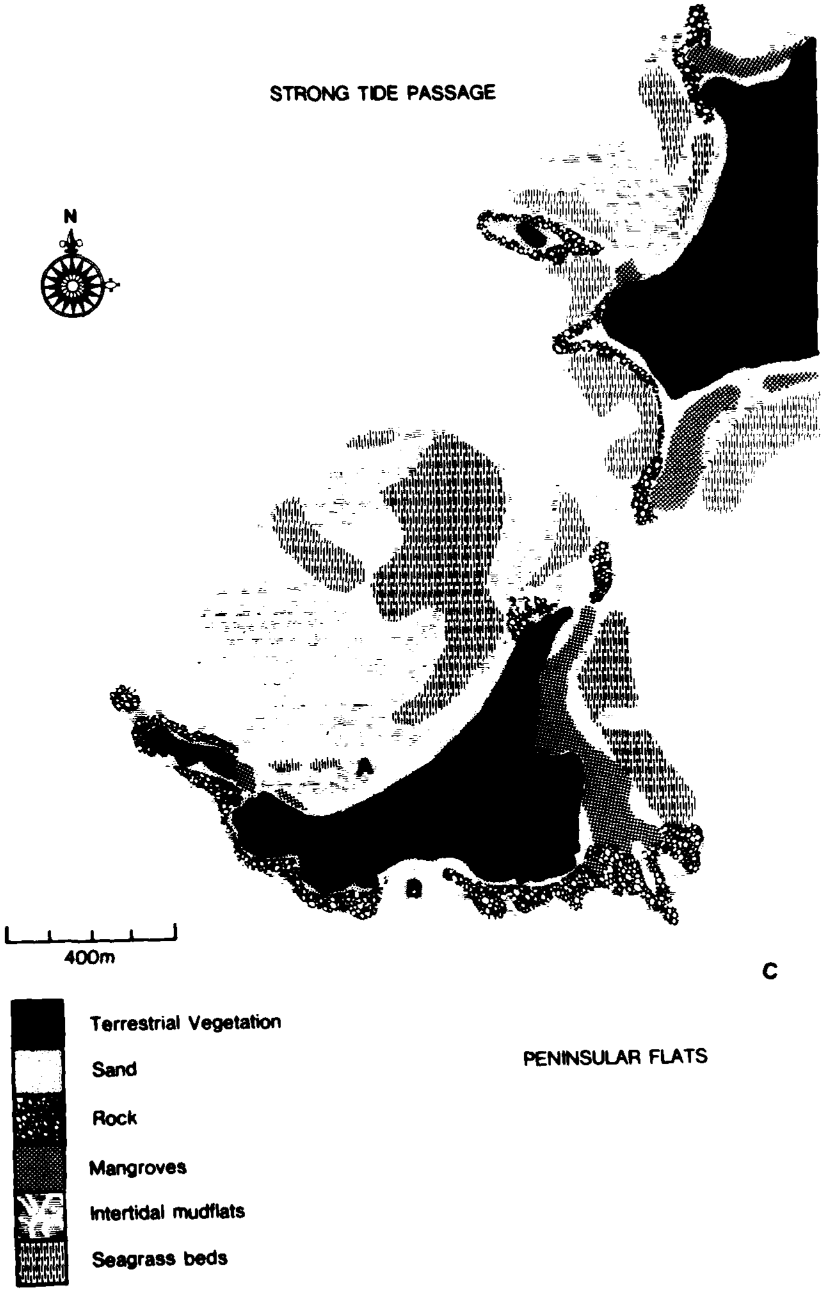


FIG. 3 - Map of the Triangular Island region showing the vegetation, types of substrata and sites of diver-training exercises

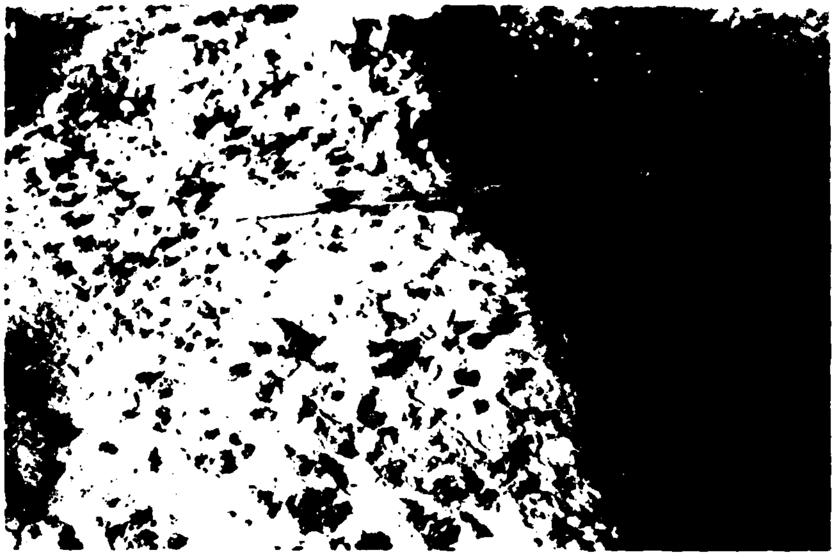
PLATE 1 - 'Little Bang' Beach looking north over the test area

(a) High tide (b) Low tide

PLATE 2 - Seagrass *Zostera capricorni* Aschers at Triangular Island

(a) Seagrass beds (S) at the eastern end of 'Little Bang' Beach

(b) *Zostera capricorni* Aschers



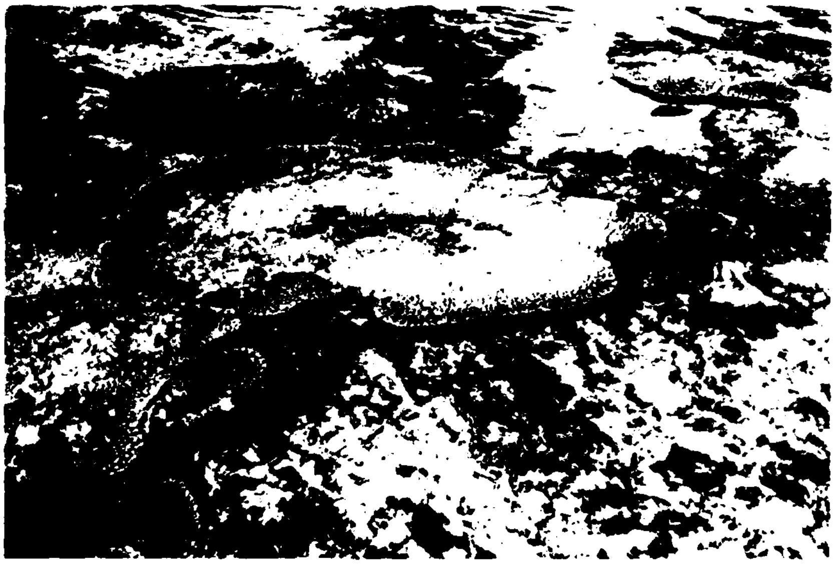


PLATE 3 - (a) Burrows and worm faeces adjacent to a blast crater on Little Bang Beach

(b) Plate coral *Acropora* sp. in a pool on the eastern side of Triangular Island.

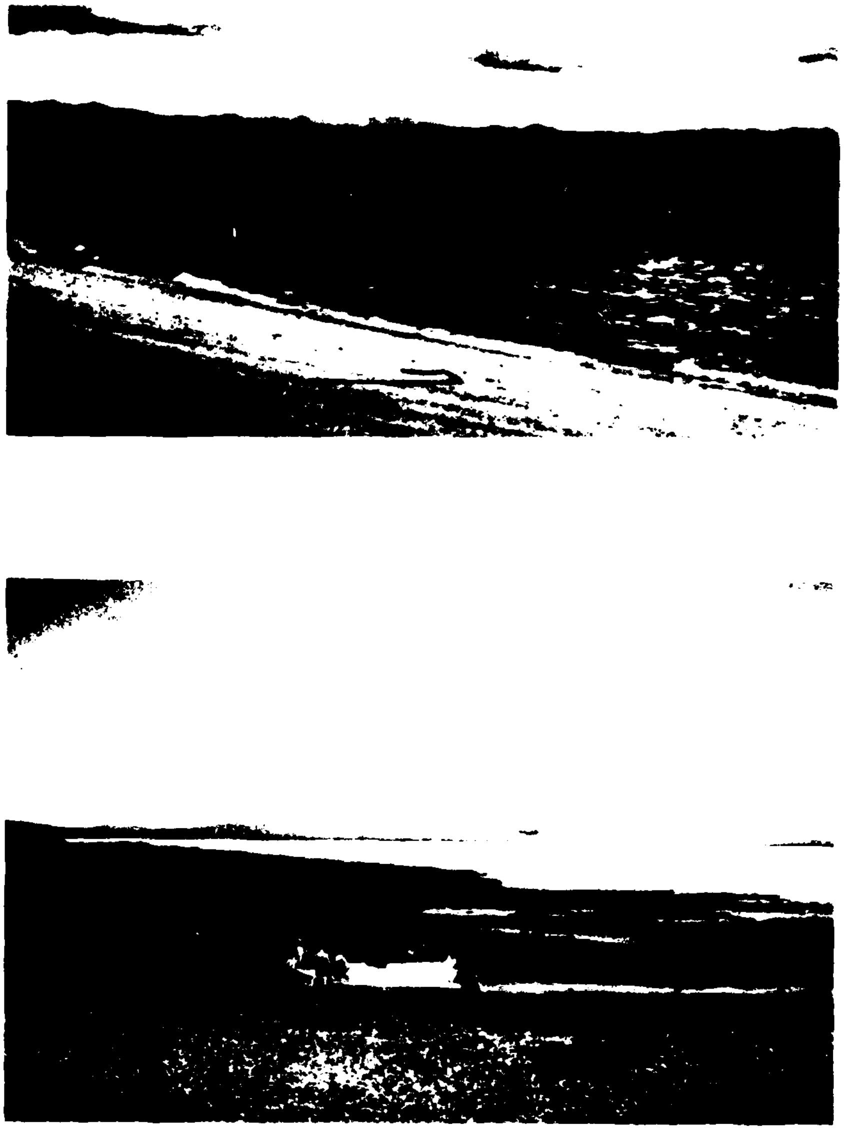


PLATE 4 - Site of the test area on 'Big Bang' Beach

(a) High Tide

(b) Low tide showing the mud and shingle substratum and the channel blasted to provide boat access to the island.

PLATE 5 - Effect of the explosion of a single detonator cord and footprints on the mud at 'Little Bang' Beach.

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