11 FISHERIES

11.1 INTRODUCTION

This Section of the EIA Report presents the findings of a desk-top assessment of the impacts of the proposed Lamma Extension project on existing fisheries resources, fishing operations and fish culture activities.

The objectives of the assessment are as follows:

- to establish the importance to Hong Kong's fisheries of the habitats which may be affected by the construction and operation of the proposed power station and associated facilities on the Lamma Extension reclamation;
- to identify fisheries sensitive receivers;
- to assess the scale of potential impacts to fisheries from the works associated with the construction and operation of the power station, and identify any significant or unacceptable impacts;
- to identify any mitigation measures and residual impacts; and
- to assess the need for a fisheries monitoring and audit programme.

11.2 LEGISLATION AND STANDARDS

11.2.1 Legislation

The criteria for evaluating fisheries impacts are laid out in the *Technical Memorandum on Environmental Impact Assessment Process* of the *Environmental Impact Assessment Ordinance (Cap 499) (EIAO TM)*. *Annex 17* of the *TM* prescribes the general approach and methodology for assessment of fisheries impacts arising from a project or proposal, to allow a complete and objective identification, prediction and evaluation of the potential fisheries impacts. *Annex 9* recommends the criteria that can be used for evaluating fisheries impacts.

Other legislation which applies to fisheries includes:

- the *Fisheries Protection Ordinance (Cap 171) 1987* which provides for the conservation of fish and other aquatic life and regulates fishing practices; and
- *Marine Fish Culture Ordinance (Cap 353) 1983* regulates and protects marine fish culture and other related activities.

11.2.2 Ex gratia Arrangements

Capture Fisheries

Fishermen do not have legal ownership of the water they habitually fish. They are, therefore, not entitled to any statutory compensation for loss of fishing grounds. However, according to existing policy, fishermen affected by reclamation or development projects may be granted *ex gratia* allowances subject to certain eligibility criteria. Since 1993, *ex gratia* allowances have been based on the notional value of three years fish catch in the gazetted works area for the proposed project under the Foreshore and Seabed (Reclamations) Ordinance (Cap 127), and should be applied to all dredging and dumping projects. Such *ex gratia* allowances serve as allowances for a permanent loss of fishing grounds and are aimed at assisting the affected fishermen in relocating their activities to other fishing grounds or to move into another industry.

Culture Fisheries

Ex gratia arrangements for mariculturists affected by dredging or dumping projects were approved in July 1993. If, at any one time, the suspended solids concentration exceeds 50 mg L^{-1} or exceeds by 100% the highest level recorded at the FCZ during the five years before commencement of works in the vicinity, mariculturists are eligible for *ex gratia* allowance payments. When such criteria are exceeded, appropriate mitigatory measures, including stopping of works if necessary, should be adopted to keep the impact within acceptable levels. Should *ex gratia* payments be triggered the eligible mariculturists may then opt to:

- continue mariculture in the same place at their own risk, in which case they would be eligible for an *ex gratia* allowance equivalent to 50 % of the normal two-year fish culture cycle; or

- suspend mariculture operations for two years, in which case they would be eligible for an *ex gratia* equivalent to the notional loss of income for a normal two-year fish cycle; or

- cease mariculture operations permanently, in which case they would receive the existing *ex gratia* allowance payable for extinguishment, which contains elements for the notional loss of income for two years and the loss of capital investment in rafts and cages.

11.3 BASELINE CONDITIONS

In Hong Kong, the commercial marine fishing industry is divided into capture and culture fisheries. To assess the capture fishery within the Study Area, the most up-to-date information on the Hong Kong fishery was consulted(1). Information from other relevant studies within the Study Area were also reviewed in order to determine if the areas are important nursery and spawning grounds for commercial fisheries(2). Mariculture information was obtained from the AFD annual report 1996-97.

11.3.1 Capture Fisheries

In 1996 the estimated fisheries production in Hong Kong waters from both capture and culture fisheries amounted to 192,160 tonnes, valued at HK$ 2,459 million(3). Capture fisheries accounted for 96% by weight of the total production

(1) Agriculture and Fisheries Department (1998) Port Survey 1996 - 1997.
(2) ERM (1998a) Fisheries Resources and Fishing Operations in Hong Kong Waters, Final Executive Summary, for Agriculture and Fisheries Department.
(3) Agriculture and Fisheries Department (1997) Annual Departmental Report 1996-1997.

while the remaining 4% corresponded to the culture sectors of the industry. The five most abundant fish species landed by weight from the capture sector were golden thread (*Nemipterus virgatus* 14%), lizardfish (*Saurida* sp 9%), big-eyes (*Priacanthus* sp 5%), scads (*Decapterus* sp 5%) and yellow belly (*Nemipterus bathybius* 4%)[1].

Fishing Operations

In 1989-91 AFD devised a system whereby the waters of Hong Kong were divided up into Fishing Zones. Data was gathered at that time on the catches of the Hong Kong fleet derived from these Fishing Zones[4]. Since this first Hong Kong wide survey AFD have updated the information which now indicates that the number of Fishing Zones equates to 189 of which 179 are actively fished by vessels in the Hong Kong fleet.

The up-to-date information from AFD is available for use in this EIA and can be collated to allow an assessment be made of the importance of Fishing Zones near Lamma Island to the Hong Kong fishery. The designated Fishing Zones within the Study Area has been identified and the importance of these zones will be assessed and discussed below.

The Study Area within which potential impacts arising from the construction and operation of the proposed power station extension may occur, consists of five Fishing Zones. These zones are found in southern Lamma, northeast Lamma and include the western coast of the Island (*Figure 11.3a* and *Table 11.3a).*

Table 11.3a ***AFD Fishing Zones within the Lamma Extension Study Area***

Code	Fishery Area	Area (Ha)
0096	Pak Kok	873.35
0097	Po Law Tsui	402.88
0098	Ha Mei	1,635.66
0099	Tai Kok	2,133.91
0109	West Lamma Channel	4,537.59

Table 11.3b shows the number of vessels operating within the waters of each AFD Fishing Zone within the Study Area.

Table 11.3b ***Number of Vessels Operating During 1996 - 1997 in Each Fishing Zone within the Lamma Extension Study Area by Length Category***

Code	Fishing Zone	Vessels < 15 m	Vessels > 15 m	All Vessels
0096	Pak Kok	66	5	71
0097	Po Law Tsui	160	20	180
0098	Ha Mei	237	58	295
0099	Tai Kok	251	65	316
0109	West Lamma Channel	130	60	190

(4) Agriculture and Fisheries Department (1991) Port Survey 1989 - 1991.

The Fishing Zones on the western coast of Lamma Island support a high number of vessels many of which are greater than 15m in length and operate using trawling gear. The number of vessels operating within the waters of these Fishing Zones is reflected in the production and catch values of the individual zones (*Table B11.3c*).

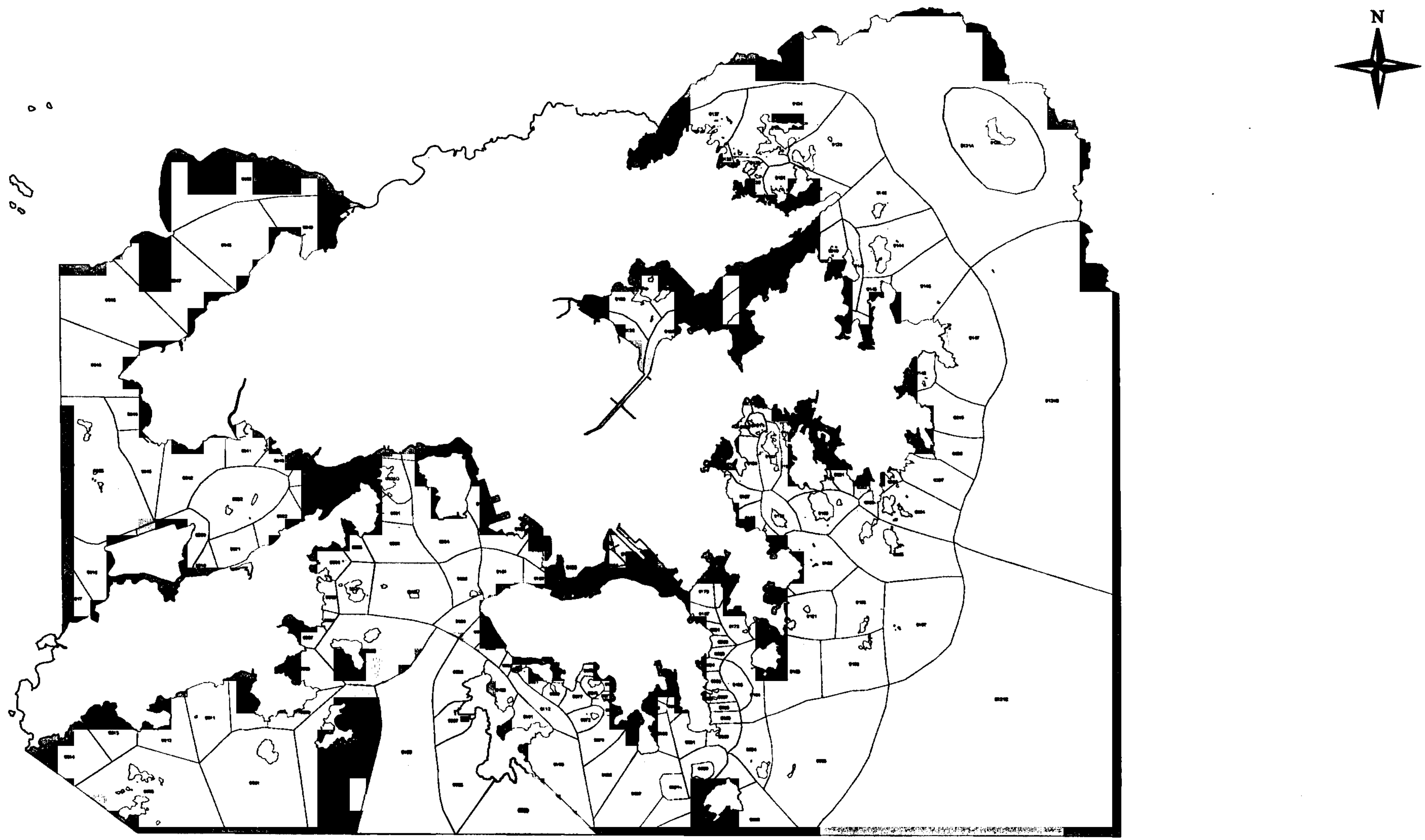

Figure 11.3a AFD FISHING ZONES WITHIN THE LAMMA POWER STATION EXTENSION STUDY AREA

Date : 30 October 1998 Reference : G:\CONTRACT\C1830\GIS\ROUTE.APR

KEY

- Proposed Lamma Power Station Extension
- AFD Fishing Zones Within the Study Area
- AFD Fishing Zones

ERM-Hong Kong Ltd.
6/F Hecny Tower
9 Chatham Road
Tsimshatsui
Kowloon, Hong Kong

ERM

Table 11.3c ***Total Value ($), Adult Catch (kg) and Fry Catch (tails) Displayed on a Total Production, Production (Ha^{-1}) and Rank (Ha^{-1}) Basis for the Fishing Zones in the Lamma Extension Study Area (all fishing vessels)***

AFD Code	Fishing Zone	Total Production			Production (Ha^{-1})			Rank Production (Ha^{-1})		
		Adult Fish (kg)	Fry (tails)	Value ($)	Adult Fish (kg)	Fry (tails)	Value ($)	Adult Fish	Fry	Value
0096	Pak Kok	64,686.73	55,544.34	1,211,979.53	74.07	63.60	1,387.73	108/210	43/89	128/210
0097	Po Law Tsui	85,552.86	62,904.34	3,073,371.69	212.35	156.14	7,628.49	43/210	39/89	27/210
0098	Ha Mei	246,277.79	79,464.34	6,078,196.23	148.93	48.05	3,675.61	66/210	45/89	70/210
0099	Tai Kok	407,638.34	86,824.34	6,884,342.15	191.03	40.69	3,226.16	50/210	49/89	84/210
0109	West Lamma Channel	504,234.67	-	8,090,005.44	111.12	-	1,782.89	87/210	-	113/210

In general the production values from within the Study Area are similar and rank highly in comparison to other areas in Hong Kong. The exception to this is the Fishing Zone on the northern tip of Lamma Island at Pak Kok. This Fishing Zone is ranked only 108 out of 179 areas for fisheries production and only 128 out of 179 area for catch value.

It is noted that the Fishing Zone at Po Law Tsui (0097) has the highest ranking in terms of production value within the Study Area due to the large catches and small area. This zone surrounds the existing power station and as a result will be the most directly affected by any works associated with the construction and operation of the power station extension.

Fishermen operating within the Study Area report catches of fish fry. The fry catches from these Fishing Zones, however, are not large and are ranked as average for Hong Kong (range = 39 to 49 out of the 89 areas in Hong Kong that report fry catches) (*Table 11.3c*).

Table 11.3d lists the five most abundant species caught within the Fishing Zones in the Study Area.

Table 11.3d ***Top Five Adult Fish (by weight) Caught in Each Fishing Zone within the Lamma Extension Study Area (high value species are underlined[5])***

Code	Fishing Area	Top Five Fish in Order (by Weight)	
		Species	**Common Name**
0096	Pak Kok	Mixed Species	
		Siganus oramin	Rabbitfish
		Eleutheronema tetradactylus	Threadfin
		<u>*Pseudosciaena crocea*</u>	<u>Yellow Croaker</u>
		Sebastiscus marmoratus	Rockfish
0097	Po Law Tsui	Mixed Species	
		Caranx spp	Scad / Crevalle
		Sardinella jussieui	Sardine
		Sebastiscus marmoratus	Rockfish
		<u>*Pseudosciaena crocea*</u>	<u>Yellow Croaker</u>
0098	Ha Mei	Mixed Species	
		Caranx spp	Scad / Crevalle
		Argyrosomus spp	Croaker
		Sardinella jussieui	Sardine
		<u>*Oratosquilla* spp</u>	<u>Mantis Shrimp</u>
0099	Tai Kok	Mixed Species	
		Caranx spp	Scad / Crevalle
		Species	**Common Name**
		Argyrosomus spp	Croaker
		Sardinella jussieui	Sardine
		<u>*Oratosquilla* spp</u>	<u>Mantis Shrimp</u>
0109	West Lamma Channel	*Sardinella jussieui*	Sardine
		Mixed Species	
		Caranx spp	Scad / Crevalle
		Argyrosomus spp	Croaker
		Caranx kalla	Shrimp Scad

Note: Mixed Species consists of juveniles of *Caranx kalla, Siganus oramin, Sardinella* spp, *Leiognathus brevirostris* and *Clupanodon punctatus*.

[5] Agriculture and Fisheries Department (1998) *op cit.*

The Fishing Zones surrounding Lamma Island have mainly low value pelagic species as their most abundant catch in terms of weight. These species such as the sardine, *Sardinella jussieui*, and the scad, *Caranx* spp, are commonly regarded as trash fish and are generally sold at a low cost ($1.6 per kg) to mariculturists as fish feed. A further trash fish group, recorded as Mixed Species, was also recorded in the top five species in terms of weight.

In summary records of fishing operations in the Study Area indicate that the area is of medium to high importance to the Hong Kong fishery. On a catch weight (ha^{-1}) basis the Fishing Zones in the LPSE Study Area rank from 43rd to 108th of the 179 fishing areas in Hong Kong. The majority of catches reported by fishermen operating in the Study Area are small fast growing pelagic species of low commercial value.

Fisheries Resources - Spawning and Nursery Areas

A previous study has shown that the southern waters of Hong Kong are not only a productive area for fisheries in Hong Kong waters, but are also a spawning ground and nursery area for important and high value commercial species[6]. The Study Areas has some of its waters within these known spawning and nursery areas. South Lamma is reported as a spawning ground for the Croaker *Johnius belengeri*, the Coastal Mud Shrimp *Solenocera crassicornis* and the Jinga Shrimp *Metapenaeus affinis*. Research has also found that South Lamma is used as a nursery ground for the Shrimps *Metapenaeopsis barbata* and *Metapenaeopsis palmensis*, the Mantis Shrimp *Oratosquilla* spp, the Goby *Oxyurichthys tentacularis*, and Croaker (Sciaenidae) and Grouper (Serranidae) fry[7].

Culture Fisheries

There are no AFD gazetted Fish Culture Zones (FCZs) within the Study Area.

11.3.2 *Sensitive Receivers*

Based on the above review of baseline fisheries conditions in the Study Area, the following fisheries sensitive receivers which may be affected by the works associated with the construction and operation of the power station extension have been identified:

- the fry capture areas of Po Law Tsui, Ha Mei Wan and Pak Kok (July and August only);
- the seasonal spawning ground in southern waters; and
- the seasonal nursery area in southern waters.

Spawning and Nursery Areas

The *EIAO Technical Memorandum* classifies spawning and nursery grounds as areas of high importance, as they are essential for the recruitment of juveniles and hence the health of adult fish stocks. The Study that identified areas in southern waters as spawning and nursery areas also highlighted the seasonal

(6) ERM (1998a) *op cit.*
(7) ERM (1998a) *op cit.*

nature of these areas[8]. Spawning of fish species is reported to occur between June to September and spawning of commercial crustacean species between June to August. Juvenile resources have been reported in the water south of the existing power station during March to September with highest abundances between June and August.

11.3.3 *Fisheries Importance*

The importance of the fisheries within the Study Area is addressed based on the baseline information provided above.

The Fishing Zones within the Study Area, situated to the north and to the west of Lamma Island are characterised as generally of high value (except for Pak Kok). The catches from these zones are composed of juvenile mixed species which are used as fish feed in mariculture. However, the size and subsequent value of the catches characterizes these Fishing Zones as of medium to high importance to the Hong Kong fishery.

The *EIAO TM* (*Annex 9*) states that nursery areas can be regarded as an important habitat type as they are critical to the regeneration and long term survival of many organisms and their populations. Part of the Study Area has been identified in previous studies as a spawning and nursery area for many commercially important species. It is considered, therefore, that during specific times of the year the southern part of the Study Area is regarded as of high value as the area may be seeding surrounding areas with juveniles of high value fish stocks.

11.4 ASSESSMENT OF IMPACTS

Impacts associated with the power station extension are divided into those occurring during the construction phase, and those in the operation phase.

Construction Phase

Impacts to fisheries resources and fishing operations arising from these works may be divided into those arising from direct disturbance to the habitat and those arising from perturbations to key water quality parameters.

Direct Impacts

Direct impacts to fisheries resources and fishing operations include habitat loss due to the dredging and reclamation associated with the proposed power station extension. The construction of the extension will lead to the permanent loss of 22 hectares of seabed. This equates to a loss of 5.5% of the Po Law Tsui Fishing Zone.

Indirect Impacts

Indirect impacts to fisheries resources and fishing operations during the construction phase include sediment release associated with the above construction projects. Potential impacts to water quality from sediment release are listed below:

(8) ERM (1998a) *op cit.*

- increased concentrations of suspended solids (SS);
- a resulting decrease in DO concentrations; and
- an increase in nutrient concentrations in the water column.

Suspended Solids: Suspended sediment fluxes occur naturally in the marine environment and consequently fish have evolved behavioural adaptations to tolerate increased SS loads, including clearing their gills by flushing water over them. Where SS levels become excessive, fish will move to clearer waters. Susceptibility generally decreases with age, with eggs the most vulnerable and the adults the least sensitive to effects from sediments. Other factors such as the rate, season and duration of SS elevations will interact with life stage sensitivity to influence the type and extent of impact upon fish.

Dissolved Oxygen: The relationships between SS and DO are complex, with increased SS in the water column combining with a number of other effects to reduce DO concentrations in the water column. Elevated SS (and turbidity) reduces light penetration, lowers the rate of photosynthesis by phytoplankton (primary productivity) and thus lowers the rate of oxygen production in the water column. Elevated SS can also cause increased energy retention from sunlight, resulting in higher temperatures, and thus the potential for lower oxygen levels as oxygen is more soluble in cold water. This has a particularly adverse effect on the eggs and larvae of fish, as at these stages of development high levels of oxygen in the water are required for growth due to high metabolic rates.

The development of critical concentration thresholds for local marine species can provide a tool to assess whether construction and operation of the power station extension and associated works may impact the ecological community. For example, acute and/or chronic effects to marine organisms may become manifest only at certain levels of contaminant concentration, and these levels may then be specified as tolerance thresholds. However, this approach is not practicable for Hong Kong waters due to lack of species threshold data specific to Hong Kong. Although literature surveys have been used in the past to fill such data gaps, many of the examples cited in these reports are derived from temperate habitats and species and their relevance to Hong Kong's marine environment is as yet undetermined. Therefore any conclusions drawn from these literature surveys are tentative and require further investigation.

As an alternative approach, species tolerances to the natural variations in the marine environment near the proposed work areas may be estimated using the maximum and minimum values recorded from baseline conditions (see *Water Quality Section Part B Section 5 Table 5.3a, Part C Section 5 Table 5.3a* and *Part D Section 4 Table 4.3a*). In the absence of more precise impact triggers, these ranges may be considered critical concentration thresholds, and impacts could be presumed to occur only at levels lying beyond the range of natural variation.

Nutrients: High levels of nutrients in seawater can cause rapid increases in phytoplankton often to the point where an algal bloom occurs. An intense bloom of algae can lead to sharp decreases in the levels of dissolved oxygen in the water as dead algae fall through the water column and decompose on the bottom. Anoxic conditions may result if DO concentrations are already low or are not replenished. This may result in mortality to fish, especially juveniles, due to oxygen deprivation. The role of nutrients in the cause of both harmful and non-harmful (but DO depleting) algal blooms is discussed in *Section 11.5*.

The results of the modelling of the sediment plumes associated with the dredging works for the reclamation have shown that the predicted maximum levels are localised to within and around the dredging works. It is expected that the concentrations within the Study Area as a whole will be maintained at environmentally acceptable levels (see *Section* 5).

Impacts to the sensitive receivers listed above in *Section 11.3.2* are predicted to be within environmentally acceptable levels (as defined by compliance with the Water Quality Objectives - WQO for the area). Concern has been raised by AFD over potential impacts to the fry capture industry that operates in Fishing Zones 0096 (Pak Kok), 0097 (Po Law Tsui) and 0098 (Ha Mei). Fishermen collect fry of various species of sea bream (eg, red pargo *Pagrus major*) during July and August. Dredging works for the power station extension during this period will involve dredging of the area in order to construct the reclamation seawalls. This is the least intensive component of the dredging operations and therefore results in the lowest losses of suspended sediment (compliant with the WQO). Consequently impacts to the seasonal fry capture fishery in these areas are considered to have been partially avoided and residual impacts are acceptable through compliance with the WQO.

Operation Phase

Cooling Water - Temperature

The existing power station uses seawater in the cooling system resulting in the discharge of large volumes of heated water. The heated waters are rapidly dispersed by surface mixing and tidal currents resulting in a body of offshore water with a surface elevated temperature of 2°C. *Section* 5 discusses this issue in more detail and presents plots illustrating the dispersion of plumes of cooling water from the existing power station.

Cooling water will be discharged during operation of the proposed power station extension. The cooling waters are expected to be discharged along with the waters discharged from the existing power station. The effects of water being discharged into the surrounding sea water at a higher temperature than ambient levels can have a marked impact on the surrounding marine ecology.

Firstly, high increases in the temperature of the water may result in a reduction of plankton in water directly surrounding the outlet which in turn results in a reduction of primary productivity and subsequently oxygen production decreases. Secondly, elevated temperatures, remote from the outfall, can lead to algal blooms, resulting in an oxygen depletion in the water column due to eventual decomposition of the algae on the seabed, as discussed above.

However, the results of the thermal plume modelling for the power station show that the cooling water effluent is not predicted to raise the temperature of the water column to any levels other than those that are already present from the existing power station. In view of the relatively small changes in the quantity of cooling water predicted to be discharged into the water column, and the resulting temperature increases, it is expected that the environmental impact of this cooling water to the fisheries within the Study Area will be minimal.

Cooling Water - Entrainment & Impingement

In the USA intake mortalities through entrainment of juvenile fish and impingement of adult fish are thought to have caused serious impacts to wild fish populations[9]. The San Onofre Nuclear Generating Station (SONGS) in California was predicted to kill 50 - 84 tonnes of juvenile and adult fish per year through entrainment into the cooling water system and impingement onto intake screens[10]. The quantity of water used in the SONGS is by a large degree greater than that to be used for the Lamma Extension. The SONGS uses approximately 7.3 million litres per minute[11] whereas the power station extension will use only 1.98 million litres per minute. (The existing power station uses approximately 5.2 million litres per minute at a maximum)

The quantity of water intaken for the power station extension is likely to be less than that taken in for the existing power station. The gas fired extension requires less cooling water than the coal fired plant and will thus intake less seawater. Impacts through entrainment and impingement of fisheries resources are not expected to deteriorate beyond existing conditions and may improve depending on how frequently the coal fired plant is used.

Cooling Water - Biocides

There are considerable operational and ecological problems caused by organisms within, and passing through power station water systems. Operationally these problems can be costly. Mussels, oysters and other marine organisms growing within cooling water circuits have resulted in losses in thermal efficiency and even total shutdowns. To counteract settling and actively growing fouling organisms, cooling water circuits are usually dosed with biocides (usually chlorine in the form sodium hypochlorite) in large amounts. This causes mortalities of both the fouling and non-fouling organisms in the circuit. The discharge of the resulting chlorinated effluents together with dead organisms may in turn have effects on the habitat beyond the outfalls. There is by necessity a close relationship between operationally necessary antifouling procedures within systems and the wider ecological consequences of the discharge.

The power station extension is predicted to discharge residual free chlorine continuously at a concentration of 0.3 mg l^{-1} in the cooling waters. This concentration is the same as the existing power station and is below EPD's[12] licence limit for discharges of 0.5 mg l^{-1}. Research has been conducted internationally on the effects of chlorine discharges on marine ecological and fisheries resources. Although no research has been conducted on local species, the international review provides data which can be used as a benchmark to evaluate potential impacts in Hong Kong. Work on the toxic effects of chlorine on fish eggs and larvae has indicated that abnormal development has occurred at concentrations of 0.31 to 0.38 mg l^{-1} (a higher concentration than that to be discharged)[13]. The effects of chlorine on adult fish indicate that lethal effects

(9) Van Winkle W (1977) Proceedings of the Conference on Assessing the Effects of Power Plant Induced Mortality on Fish Populations. Pergamon Press.

(10) NRC (Nuclear Regulatory Commission) (1981) Final Environmental Statement related to the operation of San Onofre Nuclear Generating Station Units 2 and 3. Southern California Edison Company, the San Diego Gas and Electric Company, The City of Riverside, and The City of Anaheim. US Nuclear Regulatory Commission Office of Nuclear Reactor Regulation.

(11) Ambrose RF *et al* (1996) Predicted and Observed Impacts: can we foretell ecological change? In - Detecting Ecological Impacts: Concepts and Applications in Coastal Habitats. Edited by RJ Schmitt and CW Osenberg Pages 345 - 369. Academic Press Inc.

(12) Technical Memorandum for Effluents, Section 21 Water Pollution Control Ordinance, Cap 358.

(13) Morgan RP & Prince RD (1977) Chlorine Toxicity to eggs and larvae of five Chesapeake Bay fishes. Transaction of the American Fisheries Society. 106 (4): 380 - 385.

have been report for some species at concentrations as low as 0.02 mg l^{-1}. Lethal effects on fish occur due to chlorine causing the gill epithelium to slough off followed by excessive mucous production. This causes blockage of the respiratory process (oxygen and carbon dioxide transport across the gill epithelium) and subsequent death[14].

Although the toxic effects of chlorine are increased synergistically[15] by the increases in temperature associated with cooling waters, the concentrations of residual chlorine diminish rapidly with time and distance from the discharge point[16]. The modelling exercises conducted for the water quality assessment (reported in *Section* 5) indicate that residual chlorine levels of 0.02 mg l^{-1} are only likely to occur in close proximity to the outfall, mirroring the existing power station conditions. Lethal or sublethal (effects on growth or reproduction) effects are not predicted to occur to fisheries resources as research has indicated that adult fish will avoid areas where concentrations of free residual chlorine in the water exceeds 0.035 mg l^{-1}[17].

11.5 *Red Tide Assessment*

11.5.1 *Introduction*

The Study Brief calls for an assessment of the need for examining the relationship between temperature elevation as a result of heated effluent and the occurrence of red tides. This section of the EIA fulfils this requirement by presenting the findings of a literature review of observed incidents of red tides, and the causal factors to which they have been attributed, in Hong Kong, in Southeast Asia and worldwide. Particular attention has been paid to the role of temperature elevation, whether natural or anthropogenic, in red tide events. Literature from monitoring programmes for cooling water discharges has been examined to determine whether any evidence exists for linking thermal discharges with red tide events.

11.5.2 *Background*

"Red Tide" is a term normally used to describe the rapid growth of microscopic algae (mostly dinoflagellates) which produce a characteristic pink or reddish-brown colouration in seawater[18]. Other colours such as orange, purple and yellow have also been reported for algal blooms as discolouration varies with the species of causative organism, pigments, size and concentration[19]. Most red tides represent useful contributions to plankton production[2] and have no proven adverse effects on the ecosystem. They are therefore non-harmful algal blooms. Some red tides are, however, toxic and cause damages to marine life, and are thus regarded as Harmful Algal Blooms (HABs). Other "non-red tide"

(14) Bass ML *et al* (1977) Histopathological effects of intermittent chlorine exposure on bluegill (*Lepomis macrochirus*) and rainbow trout (*Salmo gairdneri*). Water Research 11: 731-735.

(15) Cairns J *et al* (1978) Effects of temperature on aquatic organisms sensitivity to selected chemicals. Virginia Water Resources Research Center Bulletin 106 Virginia, USA.

(16) Mattice JS & Zittel HE (1976) Site specific evaluation of power plant chlorination. Journal of Water Pollution Control. 48 (10): 2284 - 2308.

(17) Grieve JA *et al* (1978) A program to introduce site-specific chlorination regimes at Ontario hydro generating stations. Pages 77-84 in Jolley RL *et al* eds (1978) Water Chlorination: Environmental Impacts and Health Effects, Volume 2 . Michigan: Ann Arbor Science.

(18) Environmental Protection Department (1996) Marine Water Quality in Hong Kong. Environmental Protection Department, Hong Kong Government.

(19) The IOC Science and Communication Centre on Harmful Algae (1998) Red tide and shellfish poisoning. wysiwyg://4//http://www.botany.uwx.ac.za/Envacts/redtides/index.htm.

phytoplankton blooms, ie, blooms which cause no discolouration of seawater (particularly those resulting from diatoms), could either be harmful (HABs) or merely be natural periodic events without any detrimental effects (Prof IJ Hodgkiss, pers comm).

Algal blooms are normally a natural phenomenon and have occurred throughout recorded history. However, in the past few decades there has been extensive evidence from around the world, including Hong Kong, to suggest that coastal marine phytoplankton blooms have increased in frequency, intensity and geographic distribution. Examples of algal blooms believed to have been induced by anthropogenic activities, include Tolo Harbour, Hong Kong[20], Chinese coastal waters[21], Japan[22][23], Adelaide estuary of South Australia[24], South African coasts[25], Bulgarian coasts[26], Danish coastal waters[27], the Gulf of Finland[28], Dutch coastal waters[29], Florida coast of USA[30] and Valparaiso Bay of Chile[31].

Two well recognized local HAB specialists, Prof IJ Hodgkiss and Dr KC Ho, have reviewed worldwide HAB incidences in subtropical waters and pointed out that HAB organisms generally have four distinct growth phases, namely, initiation, development, aggregation and dissipation[32]. Any environmental factors favouring the first three stages might lead to the formation of algal blooms.

Based on algal bloom studies conducted by many scientists from various countries, the general conditions reported for the HAB formation include hydrographic changes such as temperature[33] and salinity[34], pollution[35], nutrient enrichment[36], ratios between nitrogen and phosphorus[37], upwelling[38], current flow[39] and weather patterns[40].

(20) Lam CWY and Ho KC (1989) Red tides in Tolo Harbour, Hong Kong. In Red Tides: Biology, Environmental Science and Toxicology. (eds Okaichi T, Anderson DM and Nemoto T) p. 49-52. Elsevier, New York.

(21) Qi Y, Hong Y, Lu S and Qian H (1995) An overview of harmful algal bloom (red tide) occurrences along the coast of China and research upon them. In The Marine Biology of the South China Sea II. (eds Morton B, Xu G, Zou R, Pan J and Cai G) p. 107-110. World Publishing Corporation, Beijing, PRC.

(22) Takenchi T, Kokubo T and Uchida T (1997) Environmental features of the area where *Gymnodinium mikimotoi* appeared and continuous of reoccurrence of the red tides in Tanake Bay. Nippon Suisan Gakkaishi 63(2): 184-

(23) Koizumi Y, Kohua J, Matsuyama N, Uchida T and Honjo T (1996) Environmental features and the mass mortality of fish and shellfish during the *Gonyaulax polygramma* red tide occurred in and around Uwajima bay, Japan, in 1994. Nippon Suisan Gakkaishi 62(2): 217-224.

(24) Cannon JA (1990) Development and dispersal of red tides in the Port River, South Australia. In Toxic Marine Phytoplankton. Proceedings of the Fourth International Conference on Toxic Marine Phytoplankton (eds Graneli E, Sundstrom B, Edler L and Anderson DM) p. 110-115. Elsevier, USA.

(25) Horstman DA (1981) Reported red water outbreaks and their effects on fauna of the west and south coasts of South Africa, 1959-1980. Fish Bull S Africa 15: 71-88.

(26) Sukhanova IN, Flint MV, Hibaum G, Karamfilov V, Kopylov AI, Matveeva E, Rat'oka TN and Sazhin AF (1988) *Exuviaella cordata* red tide in Bulgarian coastal waters (May to June 1986). Mar Biol 99:

(27) Nielsen A and Aertebjerg G (1984) Plankton blooms in Danish waters. Ophelia Suppl 3: 181-188.

(28) Nemi A (1974) Primärproduktionen som kriterium vid uppskattningen av recipienters föroreningsgrad. Nordforsk Miljövards-sekretariatet Publication 4: 173-188.

(29) Cadée GC (1986) Recurrent and changing seasonal patterns in phytoplankton of the westernmost inlet of the Dutch Wadden Sea from 1969-1980. Mar Biol 93: 281-289.

(30) Steidinger KA (1983) A re-evaluation of toxic dinoflagellate biology and ecology. Prog Phycol Res 2: 147-188.

(31) Muno Z, Avaria S and Parias M (1990) Red tides in Valparaiso Region, Chile, caused by *Prorocentrum* species. Revista de Biol Mar 25(1): 109-132.

(32) Ho KC and Hodgkiss IJ (1991) Red tides in subtropical waters: an overview of their occurrence. Asian Mar Biol 8: 5-23.

(33) Tyler MA and Seliger HH (1981) Selection for a red tide organism: physiological responses to the physical environment. Limnol Oceanogr 26(2): 310-324.

(34) Cosper EM, Lee C and Carpenter EJ (1990) Novel "brown tide" blooms in Long Island embayments: a search for the causes. In Toxic Marine Phytoplankton. Proceedings of the Fourth International Conference on Toxic Marine Phytoplankton (eds Granéli E, Sundström B, Edler L and Anderson DM) p. 17-28. Elsevier, USA.

(35) Prakash A (1987) Coastal organic pollution as a contributing factor to red-tide development. Rapp P-v Réun Cons Int Explov Mer 187: 61-65.

(36) Smayda TJ (1990) Novel and nuisance phytoplankton blooms in the sea: evidence for a global epidemic. In Toxic Marine Phytoplankton. Proceedings of the Fourth International Conference on Toxic Marine Phytoplankton (eds Graneli E, Sundstrom B, Edler L and Anderson DM) p 29-40. Elsevier, USA

(37) Hodgkiss IJ and Ho KC (1997) Are changes in N:P ratios in coastal waters the key to increased red tide blooms? Hydrobiologia 352: 141-147.

(38) Tilstone GH, Figueiras FG and Fraga F (1994) Upwelling-downwelling sequences in the generation of red tides in coastal upwelling system. Mar Ecol Prog Ser 112: 241-253.

(39) Margalef R, Estrada M and Blasco D (1979) Functional morphology of organisms involved in red tides as adapted to decaying turbulence. In Toxic dinoflagellate blooms (eds Taylor DL and Seliger HH) p. 89-94. Elsevier North Holland, New York.

In his review on harmful algal blooms, Professor G Hallegraeff, an acknowledged HAB specialist, explored three explanations for the global increase in algal blooms, namely, increased utilization of coastal waters for aquaculture, transport of dinoflagellate cysts in ships' ballast waters, and stimulation of plankton blooms by "cultural eutrophication" and/or unusual climatological conditions[41].

11.5.3 *Impacts of HABs on Marine Ecosystems*

Physical Damage to Fish

Dense concentrations of HAB organisms can suffocate fish by clogging or irritating their gills, preventing them from normal respiration and potentially causing mass mortality. Other forms of damage to fish include the recently discovered feeding on fish tissue by certain dinoflagellate species resulting in the death of the fish within a few hours.

Oxygen Depletion

The mass mortality of the HAB organisms due to nutrient depletion causes a significant increase in bacteria which are responsible for organic decomposition. The activities of such a huge population of bacteria deplete the oxygen content in water and in turn, cause suffocation and even death of other organisms.

Direct Poisoning

Some dinoflagellate species, eg, *Alexandrium catenella*, produce neurotoxins which disrupt nervous functions and have caused mass marine mortalities along the South African coast.

Indirect poisoning

Organisms such as mussels, clams and oysters are particularly vulnerable to HABs, because they feed by filtering particles, including phytoplankton. Toxic microalgal particles accumulate in the digestive system of these filter-feeders and subsequently cause illness or death to such consumers as birds, marine mammals and humans.

11.5.4 *International Review*

The following presents a review of the occurrence of HABs internationally. The review provides background information from case studies and discusses the factors thought to be involved in the occurrence of these blooms. *Figure 11.5a* [42] illustrates the locations worldwide where HABs and fishkills have been reported.

(40) Rabbani MM, Rehman AU and Harms CE (1990) Mass mortality of fishes caused by dinoflagellate bloom in Gwadar Bay, Southern Pakistan. In Toxic Marine Phytoplankton. Proceedings of the Fourth International Conference on Toxic Marine Phytoplankton (eds Granéli E, Sundström B, Edler L and Anderson DM) p. 209-214. Elsevier, USA

(41) Hallegraeff GM (1993) A review of harmful algal blooms and their apparent global increase. Phycologia 32: 79-99.

(42) Sundström B, Edler L and Granéli E (1990) The global harmful effects of phytoplankton. In Toxic Marine Phytoplankton. Proceedings of the Fourth International Conference on Toxic Marine Phytoplankton (eds Granéli E, Sundström B, Edler L and Anderson DM) p. 541. Elsevier, New York.

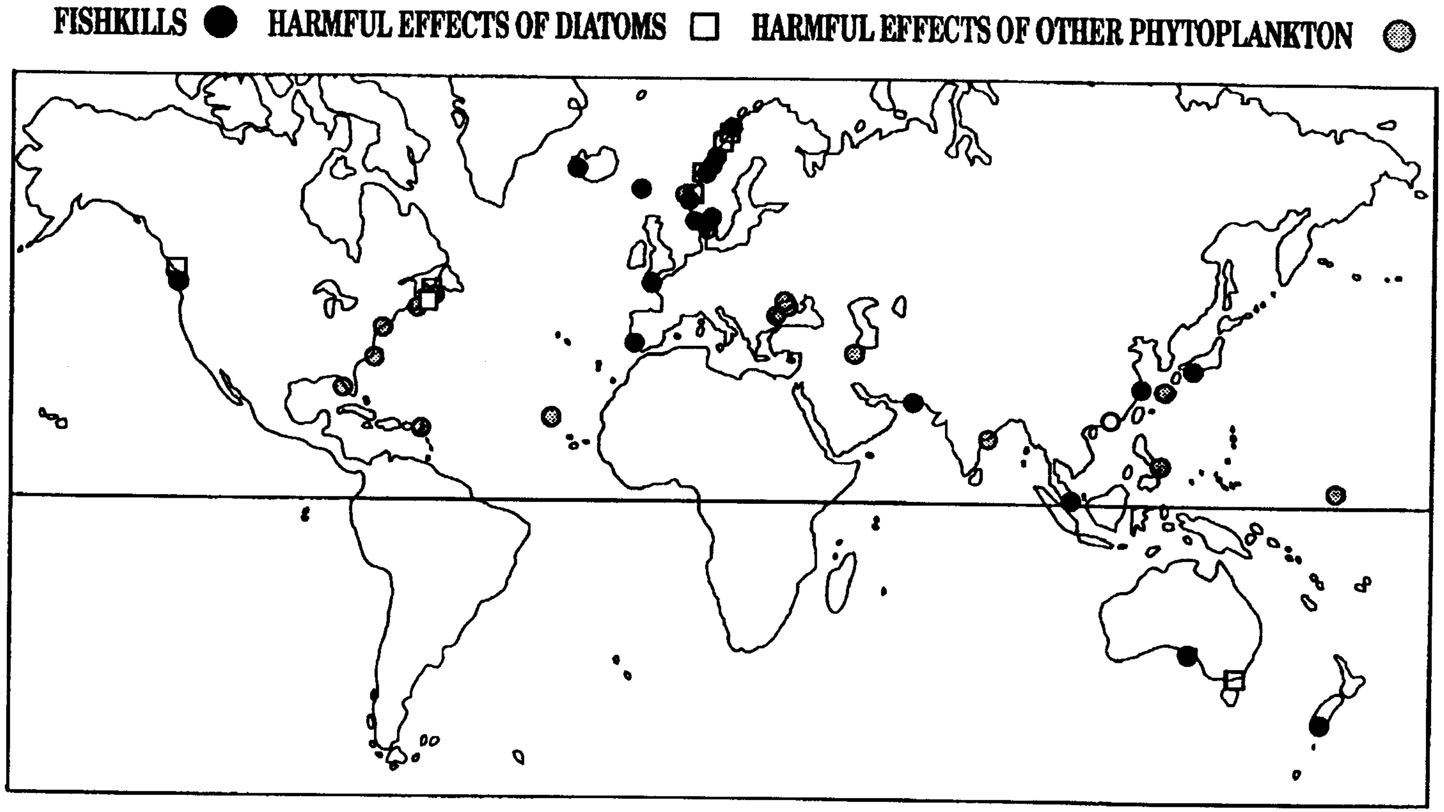

FIGURE 11.5a

GLOBAL DISTRIBUTION OF FISHKILLS AND HARMFUL EFFECTS OF DIATOMS AND OTHER PHYTOPLANKTON EXCEPT DINOFLAGELLATES

(NEW RECORDS FROM NOV. 1987 TO JUNE 26-30,1989)

FILE: C1830/C1830V
DATE: 15/10/98

Environmental
Resources
Management

ERM

Japan

A persistent HAB of *Gonyaulax polygramma* occurred in and around Uwajima Bay during late August and mid November 1994 and caused mass mortalities of cultured and natural fish and shellfish[6]. The research team of the Ehime Prefectural Fisheries Station in Japan has undertaken detailed investigation on the incident aiming to elucidate the possible factors leading to the outbreak. The meterological and hydrographical data suggested that low rainfall, high water temperature and a low water exchange rate enhanced the initial occurrence and contributed to the duration of the HAB.

Malaysia

HABs caused by the dinoflagellate *Peritoneum bahamense* have been frequently recorded in coastal waters of Sabah since 1976[43]. The marine laboratory of the University of Boston has researched into the possible factors leading to such phenomenon and has concluded that HABs were more likely to occur in months when the nutrient poor surface waters were mixed with nutrient rich deeper waters during moderate wave action.

Pakistan

Based on the observations made by Rabbani et al on the dinoflagellate bloom, *Prorocentrum minimum* in the waters of Gwadar Bay in Pakistan in November 1987, it was concluded that the relatively high temperatures of the surface water in the bay associated with high light intensity and moderate winds (ie moderate wave action) were initiative factors to the development of the bloom[23].

Bulgaria

In November 1984 an HAB caused by *Prorocentrum micans* and *Exuviaella cordata* was observed in Varna Bay[44]. A bloom of *Exuviaella cordata* was recorded again in Burgas Bay during May and June 1986[9]. Environmental conditions thought to contribute to the formation of the HAB included a high eutrophication level, water temperature not lower than 20°C, relatively low salinity (11 - 15%), irradiance not lower than 600 000 lux and calm weather. The research indicated that HABs are not likely to occur in still or calm water unless conditions are highly eutrophic.

Chile

HAB specialists of the Institute of Oceanography of the University of Valparaiso, Chile have investigated the plausible causes of the *Prorocentrum* blooms in Valparaiso Bay in March of 1983 and 1985[14]. Their measurements of *in situ* temperature and satellite information manifested a direct relation between the presence of HAB event and the associated high sea surface temperatures.

(43) Usup G and Lung YK (1991) Effects of meteorological factors on toxic red tide events in Sabah, Malaysia. Mar Biol 12(4): 331-340.

(44) Petrova-Koradjova V (1984) Red tide caused by *Prorocentrum micans* Ehr. and *Exuviaella cordata* Ostf. in Varna Bay and coastal waters in November 1984. Hydrobiologia 26: 70-74.

Mexico

The Baja California Peninsula of Mexico has witnessed several toxic algal blooms during 1992 to 1995. Ochoa et al from the Centre for Biological Research have investigated the possible causes of the HAB events and considered them as periodical and natural rather than induced[(45)]. They reported that the blooms were specially frequent in cooler months, in which temperature, marine currents, and nutrients favoured the bloom.

South Africa

The high nutrient content in upwelled water, together with the optimum combination of temperature, salinity and light, triggered the germination of the dinoflagellate cysts. This initiated the dinoflagellates to grow and divide rapidly causing a bloom along the Cape of Good Hope's west and south coastal areas in late summer and autumn[(2)].

United States of America

Tyler and Seliger from the Chesapeake Bay Institute and McCollum-Pratt Institute have studied the changes in the environmental conditions which have, contributed to blooming of the HAB organism, *Prorocentrum mariae-lebouriae* in Chesapeake Bay, USA[(16)]. Their results indicated that temperature elevation by 6°C resulted in a threefold increase in the growth rate of the organism. This, as they suggested, implied that temperature is the controlling factor in the initial blooming of *Prorocentrum* in the bay.

In his study on the correlation between water temperature and blooming of the dinoflagellate *Gymnodinium breve* in the Gulf of Mexico, Baldridge (1975) has discovered an empirical relationship between patterns of elevated surface water temperatures and subsequent occurrence of major HAB events[(46)].

The HAB research team (Oguri et al) of the University of Southern California has performed a detailed investigation on the algal blooms which occur periodically in San Pedro Bay, Southern California, USA[(47)]. The study has revealed five essential conditions which were found conducive to the HAB phenomenon in the bay area. The conditions were:

- the presence of the HAB organisms;
- low circulation;
- adequate nutrients;
- stirring mechanism (eg wave action); and
- warm temperatures.

The team also suggested that warm water effluents from cooling systems of power plants could also be a potential triggering mechanism for HABs. Warm cooling ponds or patches of water may provide a microcirculation, and may also stimulate reproductive cycles in phytoplankton.

(45) Ochoa JL, Sanchez-Paz A, Cruz-Villacorta A, Nunez-Vazquez E and Sierra-Beltran A (1997) Toxic events in northwest Pacific coastline of Mexico during 1992-1995: origin and impact. Hydrobiologia 352: 195-200.

(46) Baldridge HD (1975) Temperature patterns in the long-range prediction of red tide in Florida waters. In Proceedings of the First International Conference on Toxic Dinoflagellate blooms (ed LoCicero VR) p. 69-79. Massachusetts Science and Technology Foundation.

(47) Oguri M, Soule D, Juge DM and Abbott BC (1975) Red tides in the Los Angeles-Long Beach Harbour. In proceedings of the First International Conference on Toxic Dinoflagellate blooms (ed LoCicero VR) p. 41-46. Massachusetts Science and Technology Foundation.

11.5.5 *HABs in Hong Kong*

An intensive study of phytoplankton dynamics in Tolo Harbour was carried out between January 1983 and February 1985 by the research team of the University of Hong Kong[48]. Hodgkiss and Chan attributed the increase in total phytoplankton standing crop and changes in the species composition (from diatom to dinoflagellate) to the increasing nutrient levels in the harbour, coupled with temperature and optimum light regime (14.3 klux). A three-month HAB bloom of *Gonyaulax polygramma* occurred in Tolo Harbour from February to mid-May 1988[49]. Investigation performed by the Environmental Protection Department revealed that the eutrophic conditions of Tolo Harbour, the uniform meteorological conditions, cool temperatures, overcast skies and low precipitation favoured the development of the bloom.

A massive algal bloom, produced by, what has tentatively been identified as *Gyrodinium aureolum*, occurred in April 1998 and killed 1,500 tons of mariculture fish[50]. The bloom is thought to have been aggravated by organic pollution, and warm air and low wind may have also contributed to conditions which allowed for the further spread of the HAB. The most recent available EPD report on the marine water quality in Hong Kong states that in 1996, there was a total of 25 reported HAB cases with 13 incidents detected in Tolo Harbour. The most common causative species was the dinoflagellate *Noctiluca scintillans*. *Figure 11.5b*[51] details the frequency and distribution of HABs in Hong Kong from 1980 to 1997. *Table 11.5a* presents information gathered from EPD's latest report that details the dominant algal species associated with HABs in Hong Kong.

Table 11.5a ***The dominant algal species associated with HABs in Hong Kong***

Water Control Zone	Species name
Tolo Harbour & Channel	*Chaetoceros* sp.
	Chaetoceros pseudocrinitus
	Leptocylindrus minimus
	Noctiluca scintillans
	Pedinomonadaceae species
	Peridinium triquetra
	Plagioselmis prolonga
	Prorocentrum minimum
	Rhizosolenia fragilissima
	Skeletonema costatum
	Thalassiosira mala
	Thalassiosira spinulata
Mirs Bay	*Noctiluca scintillans*
	Rhizosolenia fragilissima
Port Shelter	*Noctiluca scintillans*
	Trichodesmium sp.
Southern	*Nitzschia delicatissima*
	Noctiluca scintillans
	Trichodesmium sp.

(48) Hodgkiss IJ and Chan BSS (1987) Phytoplankton dynamics in Tolo Harbour. Asian Mar Biol 4: 103-112.
(49) Lam CWY and Yip SSY (1990) A three month red tide event in Hong Kong. In Toxic Marine Phytoplankton. Proceedings of the Fourth International Conference on Toxic Marine Phytoplankton (eds Granéi E, Sundström B, Edler L and Anderson DM) p. 209-214. Elsevier, USA.
(50) Tan EL (1998) "Red tide" kills 1,500 tons of HK fish. http://www.redtide.whoi.edu/hab/n...oreign/hongkong/hongkong4-13-4.html.
(51) Environmental Protection Department (1997) Marine Water Quality in Hong Kong. Environmental Protection Department, The Hong Kong Government, Hong Kong.

11.5.6 *Causal Factors of HABs*

HABs are caused by a complex of factors including natural, such as hydrographic and meteorological changes, and anthropogenic (eg pollution).

Nutrients

Nitrogen and phosphorus are important factors affecting phytoplankton growth. In Tolo Harbour, Hong Kong, there was an increase in HAB blooms from two in 197 78 to 17 in 1984, and an increased contribution of dinoflagellate abundance from 26 to 66% of the phytoplankton population in the harbour. These changes were attributed to a ten-fold increase in mean phosphate levels and a five-fold increase in mean nitrate levels between 1978 and 1985[52].

Smayda (1989) stated that there is general consensus that phytoplankton (and thus HAB) growth in the sea is often nutrient limited[53]. When large amounts of nutrients are available, these opportunistic organisms utilize the excess nutrients to divide and grow at high rates, ultimately causing a bloom to form.

The semi-enclosed topography, together with high nutrient levels in the bay area allowed high proliferation of *Gymnodinium mikimotoi* in Tanabe Bay, Japan[5]. High availability of ammonium and organic carbon, resulting from upwelling due to wind, together with rapid circulation and reduced mixing of water, are plausible factors leading to the blooming of *Gymnodium catenatum* in Spain[54].

Pollution

Since dinoflagellate blooms correspond to high organic loading in sea water, sewage outfall discharges introducing substantial amounts of organic material may contribute to noxious HAB blooms[55]. Some scientists indicated that pollution, including sewage and agricultural runoff, fuels cells to divide and grow into harmful algal bloom[56].

Ballast waters

Some scientists believe that the transport of dormant cysts in the ballast tanks of ships may contribute to the spreading distribution of HAB outbreaks[57]. Zhang has shown how both harmful dinoflagellates and diatoms were carried in container ship ballast water when they travelled between Oakland and Hong Kong[58].

(52) Chan BSS and Hodgkiss IJ (1987) Phytoplankton productivity in Tolo Harbour. Asian Mar Biol 4: 79-90.

(53) Smayda TJ (1989) Primary production and the global epidemic of phytoplankton blooms in the sea: A linkage? In Novel Phytoplankton Blooms (eds Cosper EM, Briceli VM, Carpenter EJ) p. 449-483. Springer Verlag.

(54) Prego R (1992) Flows and budgets of nutrient salts and organic carbon in relation to a red tide in the Ria of Vigo (NW Spain). Mar Eco Prog Ser 79: 289-302.

(55) Scotts P (1998) Tracking the algal bloom. http://archive.abcnews.com/sectio...e/DailyNews/algaebloom980917.html.

(56) ABCNews (1998) A deadly mystery - clearing up red tide. http://archive.abcnews.com/sections/science/DyeHard/dye67.html.

(57) Science News Online (1997) Dinoflagellate. http://www.sciencenews.org/sn_arc97/9_27_97/bob1.htm.

(58) Zhang F (1997) Harmful algae from container ballast water taken from the open ocean and from Oakland California (May 1996 to April 1997). M Phil Thesis, The University of Hong Kong. 93pp.

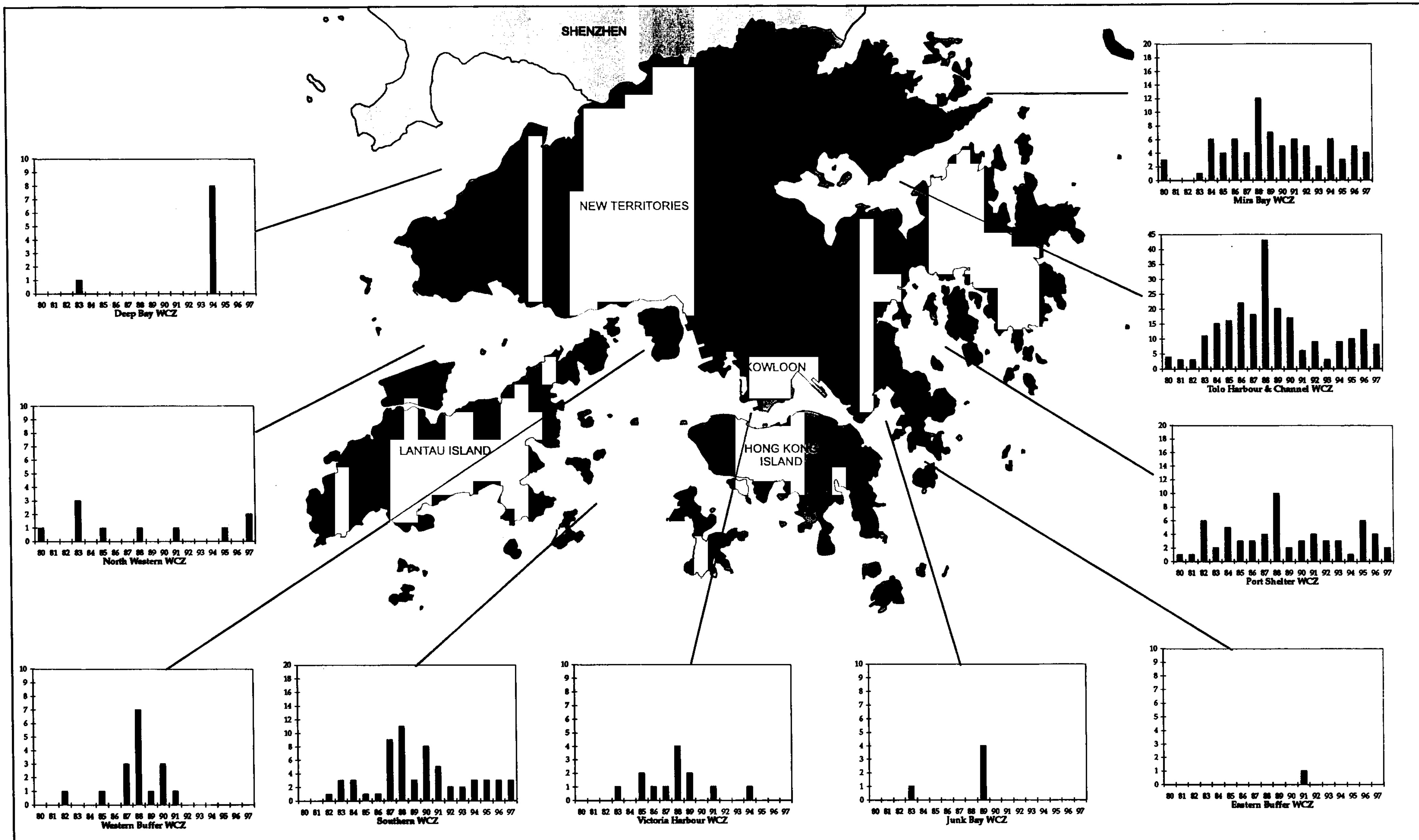

FIGURE 11.5b

RECORDED RED TIDE INCIDENTS IN HONG KONG FROM 1980 TO 1997

SOURCE: AGRICULTURE AND FISHERIES DEPARTMENT AND ENVIRONMENTAL PROTECTION DEPARTMENT
(Y-AXIS = FREQUENCY)

FILE: C1830/C1830V6
DATE: 15/10/98

Environmental Resources Management

ERM

Temperature

A rise in temperature generally increases the metabolic rate, and thus the growth rate, of phytoplankton. The effects of temperature are explored further in the following section.

11.5.7 *Temperature and HABs*

Temperature is a particularly important environmental variable in aquatic ecosystems. Introduction of thermal effluents into aquatic systems may affect organisms and create potential thermal pollution problems[59]. Currently, the most common industrial source of thermal pollution is the electric power industry in which cooling water is used to absorb the heat produced from electric generators[60]. In a review on the ecophysiology and bloom dynamics of *Heterosigma akashiwo* (Raphidophyceae), Smayda, an internationally recognized authority in phytoplankton bloom dynamics, concluded that temperature is a major factor in growth and seasonal bloom cycle[61].

The following includes a review of case studies of HABs and the effects of effluents from power stations on phytoplankton populations.

Belgium - Tihange Nuclear Power Plant

Impacts of the thermal effluent from the nuclear power plant on the phytoplankton of the Meuse River were assessed by Descy and Mouvet (1984)[62]. Phytoplankton species composition and biomass were measured during the period from 1976 to 1981 and the results showed that a mean elevation of temperature by 2 to 3°C has slight immediate effect on the phytoplankton standing crop. Shifting of species composition from the sensitive, less tolerant, diatoms to the more tolerant species was detected in areas with low water flow. Despite the slight influence of thermal discharge on the biota in the system, the researchers stressed the importance of synergistic effects of elevated temperature with other pollutants which may result in more significant impacts on the ecosystem.

Canada - Wabamun and Sundance Power Stations

The Wabamum Power Station is situated near Kapasiwin Bay in Alberta, Canada and began operation in 1956. The Sundance station lies close to Goosequill Bay and commenced operation in late 1970. Both stations use waters of Lake Wabamun as cooling water for their condensers[63]. Professor Michael Hickman of the University of Alberta has conducted a large scale study on the effects of the discharge of thermal effluent from a power station on the algal communities in Lake Wabamun[64]. The results indicated that the phytoplankton standing crops, largely composed of the diatom, *Navicula cuspidata* and the blue-green algae *Oscillatoria amoena* and *O. borneli*, were increased significantly by the

(59) Warren CF (1971) Biology and water pollution control. Saunders, Philadelphia, Penn 434pp.

(60) Parker FL and Krenkel PA (1969) Engineering aspects of thermal pollution. Vandebilt University Press nashville, Tenn 351pp.

(61) Smayda TJ (1997) Ecophysiology and bloom dynamics of *Heterosigma akashiwo* (Raphidophyceae). p 113-131.

(62) Descy JP and Mouvet C (1984) Impact of the Tichange nuclear power plant on the periphyton and the phytoplankton of the Meuse River (Belgium). Hydrobiologia 119: 119-128.

(63) Gallup DN and Hickman M (1975) Effects of the discharge of thermal effluent from a power station on Lake Wabamun, Alberta, Canada - limnological features. Hydrobiologia 46: 45-69.

(64) Hickman M (1974) Effects of the discharge of thermal effluent from a power station on Lake Wabamun, Alberta, Canada - The epipelic and epipsamic algal communities. Hydrobiologia 45: 199-215.

discharge of thermal effluent into the lake, particularly in the discharge canal of the station.

Finland - Nuclear Power Plant

The Finnish Centre for Radiation and Nuclear Safety has carried out ecological investigations in the sea areas off two stations, in Loviisa and Olkiluoto. These investigations complement monitoring programmes to document all the environmental impacts of the power plants (including thermal effects)[65]. The results showed that thermal discharges at Loviisa have elevated the mean surface water temperature by 2 to 4°C at a distance of 0.5 km from the outlet. The most obvious change in biota specifically caused by warm water has been the significant increase of littoral vegetation in the vicinity of the cooling water outlets at both stations. Primary production of phytoplankton doubled or even trebled in the study areas and this was attributed to the eutrophication conditions in the areas rather than thermal effluents from the power plants.

France - Power Station near River Loire

Site investigations on thermal effects of power station effluents on phytoplankton of the River Loire have been carried out by various research groups and different results were obtained. Khalanski and Renon[66] have reported only slight changes on the population while Talmage and Coutant[67] indicated that phytoplankton growth is generally stimulated with a reduction in the number of species. The rapid proliferation of microalgae may lead to an increase of eutrophication in the affected area.

Korea - Kori Nuclear Power Plant

Shim et al (1991) of the Seoul National University have undertaken an investigation on the effects of thermal effluent from the Kori Nuclear Power Plant on the phytoplankton levels in adjacent waters[68]. Chlorophyll *a* levels and primary productivity were measured. The results showed that the chlorophyll *a* contents were generally low with eutrophic levels being occasionally recorded, suggesting little thermal impacts from the effluents.

USA - San Onofre Nuclear Generating Station

The San Onofre Nuclear Generating Station is located on the California coast between San Diego and Los Angeles, USA. The Final Environmental Impact Statement reported a wide range of possible thermal effects on the marine environment[69]. It was predicted that the species composition of phytoplankton would be affected and that perhaps a stimulation of HABs arising from increased water temperature would result. These effects were expected to be localized and the phytoplankton population as a whole was not expected to be adversely affected. The results of Marine Review Study on the ecological effects of the power plant showed that adverse effects on phytoplankton were few and there

(65) Ilus E, Ikäheimonen TK and Klemola S (1997) Nuclear power and the environment in Finland - with special emphasis on the marine environment. http://www.geirik.is.nsfs.ilus.htm.

(66) Khalanski M and Renon JP (1977) Evolution de la teneur en pigments planctoniques dans la Loire entre Dampierre-en-Burly et Montsoreau. Can Lab Montereau 5: 37-84.

(67) Talmage SS and Coutant CC (1978) Thermal effects. J Wat Poll Contr Fed 1978: 1514-1554.

(68) Shim JH, Yeo HG and Shin YK (1991) Ecological effect of thermal effluent in the Korean coastal waters: I. Significance of autotrophic nano and pico plankton in the adjacent waters of Kori nuclear power plant. J Ocean Soc Korea 26(1): 77-82.

(69) Kastebdiek J and Parker KR (1988) Interim technical report to the California Coastal Commission. 4. Plankton. Marine Review Committee Inc.

was no suggestion that the total density of phytoplankton changed appreciably due to the operation of the power station.

Spain - Vandellos Nuclear Power Plant

The Vandellos Nuclear Power Plant complex is located in the Gulf of San Jorge between Cape Salon and Cape Tortosa, Spain. Impacts of thermal effluents from cooling systems of the nuclear power plant were assessed by Pallester and Castellvi (1980). Mechanical, thermal and chemical impacts were significant with regard to phytoplankton populations[70]. A significant decline (averaging 44%) in primary productivity was found in the vicinity of the thermal discharge area.

Chinese Taipei - Power Plant

Chen (1992) has studied the possible impacts of thermal effluent from a power plant on phytoplankton assemblages in coastal waters. The results showed that the phytoplankton assemblages were influenced by nutrient factors and hydrographic regimes, especially temperature[71]. Seasonal variation of temperature affected the distribution of phytoplankton. The results also suggested that the discharge of thermal effluent has little influence on the diversity of phytoplankton and the impact of thermal shock did not necessarily cause death to stressed phytoplankton.

United Kingdom - Nuclear Power Station in North Wales

The nuclear power station is adjacent to Lake Trawsfynydd which acted as a cooling pond for the station. Whitehouse (1971) conducted extensive studies on the biology of the Lake and the effects of thermal discharge on the lake fauna and flora[72]. The results of the investigation showed that the change in the phytoplankton composition was more closely connected with the large quantities of nutrients from fertilizer than the warming of the water by the power station.

Experiments on the effects of heated waters on phytoplankton community

The Chalk River Nuclear Laboratories of Atomic Energy of Canada Limited in Ontario, Canada, have carried out experiments on the effects of the depth of the cooling water intake and controlled discharge of heated waters (ΔT - 10°C) on a natural phytoplankton community in a cold water lake[73]. The results showed that phytoplankton numbers increased significantly when cooling waters were taken in at the lake surface and discharged at the surface. The least alteration to the phytoplankton community in the lake occurred when cooling waters were removed from deeper layers and discharged to the surface.

(70) Pallester A and Castellvi J (1980) Hydrographic and biological study of the Spanish Continental platform: Gulf of San Jorge (February 1975 - October 1996). Informes Technicos del Instituto de Investigaciones Pesqueras 76: 1

(71) Chen YLL (1992) Factors affecting the phytoplankton assemblages in a tropical coastal water influenced by thermal effluent of a power plant. Bull Plankton Soc Japan 39(1) 25-39.

(72) Whitehouse JW (1971) Some aspects of the biology of Lake Trawsfynydd; a power station cooling pond. Hydrobiologia 38: 253-288.

(73) McMahon JW and Docherty AE (1978) Phytoplankton and cooling systems: temperature effects using different intake and discharge depths. Wat Res 12: 925-929.

11.5.8 *Summary*

This review of international literature concerning harmful algal bloom (HAB) outbreaks indicates that a combination of factors are involved in causing HABs. Information from the literature suggests that temperature elevated discharges are not thought to be the primary cause of HABs. Suitable conditions for HABs arise when the levels of nutrients (nitrate:phosphate ratio), organic loading, presence of HAB cysts, mixing of the water column and temperature occur in the optimum combination. Reports concerning the effect of heated effluent on HABs and phytoplankton indicate that although small increases in temperature can increase the growth rate of these planktonic organisms, the high temperatures of most power station discharges inhibit phytoplankton growth.

The discharges from the Lamma Power Station will be released near the surface and consequently are not predicted to cause any disturbance to the seabed sediments (potentially containing HAB cysts) in the vicinity. The surface release of the discharges will also prevent disturbance of the lower layers of the water column preventing significant vertical mixing and will prevent disturbance of seabed sediment around the outfall. The intake pipes are located a minimum of 2 m above the seabed in order to limit the intake of suspended sediments (and suspended HAB cysts). These design constraints together will act to minimise the intake, subsequent discharge and germination of cysts of HAB forming organisms. Wave action will not influence the amount of vertical mixing as the outfall is sheltered and located in sufficiently deep water.

In conclusion, the review has indicated that elevated temperatures in the absence of upwelled nutrients are not likely to initiate HAB events. A combination of high temperatures and upwelled nutrients is not predicted to occur as a result of discharge design constraints as discussed above.

11.6 EVALUATION OF IMPACTS

From the information presented above, the fisheries impact associated with the construction and operation of the power station extension is considered to be low. An evaluation of the impact in accordance with *Annex 9* of the *EIAO TM* is presented below.

- *Nature of impact:* Permanent impacts will occur as a result of loss of fishing grounds in the area to be reclaimed for the power station extension. Temporary impacts to pelagic and demersal fisheries resources as a result of minor perturbations to water quality are predicted to occur only in the vicinity of the power station. Discharges of heated water are not predicted to be less than existing levels, whereas discharges of residual free chlorine are only predicted to slightly exceed existing levels. Impacts of these discharges to fisheries resources will occur only in the immediate vicinity of the outfall.

- *Size of affected area:* The main areas affected by the construction of the power station extension are 22 hectares of fishing ground within the Po Law Tsui Fishing Zone. Sediment dispersed during construction of the extension will cause short term increases in suspended sediment (SS) levels close to the works activities which cause short term exceedances (2 hours in duration) of the WQO. Operational impacts are predicted to be within acceptable levels and located within the immediate vicinity of the power station. Heated water discharges under the existing power station that exceed the WQO of 2°C elevation cover a sea area of less than 10.1 km^2 during spring tides in the wet season. Operation of the existing power station and the power station extension together will produce discharges that exceed the WQO over a sea area of less than 7.8 km^2 during spring tides in the wet season. This represents a 23 % reduction in the area of sea exceeding the WQO and confirms the acceptability of the heated water discharges from the proposed extension. Discharges of chlorine from the existing power station extend 700m from the outfall at a level of 0.01 mg L^{-1}. The extension will additionally produce a discharge of chlorine at 0.01 mg L^{-1} that extends 200m from the outfall (in a different location than the existing discharge). It is not expected that this extra discharge will cause unacceptable impacts to fisheries resources.

- *Size of fisheries resources / production:* The Po Law Tsui Fishing Zone is most affected by the construction and operation of the power station. Production from this zone is ranked as high for Hong Kong (43 out of 179).

- *Destruction and disturbance of nursery and spawning grounds:* The waters of the LPSE Study Area are recognised spawning and nursery grounds for commercially important species. The important grounds for the production of fish stocks are seasonal with the major spawning and nursery months being March through to September (fry capture is during July and August). As the water quality modelling shows that SS elevations are predicted to be within acceptable levels impacts to juvenile resources are not predicted to occur. Mortality of fish eggs and larvae in cooling water intakes is predicted to decrease over time as less water is needed to cool the gas-fired extension than the existing power station. Literature reviews have shown that fish fry and eggs are more tolerant than adults with toxic effects observed at concentrations > 0.3 mg L^{-1} (a higher concentration than that to be discharged).

- *Impact on fishing activity:* The area to be reclaimed for the power station extension translates into the loss of 5.5 % of the Po Law Tsui Fishing Zone and a potential loss of 4,671 kg annually of fish catches worth HK$ 167,806. This equates to a 0.05% decrease in the value of the Hong Kong fishery and is regarded as low. Fishing vessels that use the area are based in Aberdeen, Cheung Chau and Luk Chau. The fleets in the former two ports spend the majority of their time fishing outside of Hong Kong waters and hence the loss of 5.5 % the Po Law Tsui Fishing Zone is unlikely to seriously impact catches. However, the 184 P4/7 vessels from Luk Chau, however, depend on the whole Po Law Tsui Fishing Zone for approximately 11 % of their annual catch and consequently are most likely to be affected by the reclamation. These permanent losses may be subject to claims for *ex gratia* allowances which are administered by the Planning Environment and Lands Bureau.

- *Impact on aquaculture activity:* There are no gazetted Fish Culture Zones within the Study Area and, therefore, no impacts are predicted to occur. The findings of the red tide assessment indicate that thermal discharges are not the primary cause of red tides. The assessment concluded that the discharges from the power station extension are unlikely to cause red tides.

11.7 SUMMARY OF MITIGATION MEASURES

In accordance with the guidelines in the *EIAO TM* on fisheries impact assessment the general policy for mitigating impacts to fisheries, in order of priority, are avoidance, minimization and compensation.

Impacts to fisheries resources and fishing operations have largely been avoided during construction through constraints on the works operations associated with the sand filling for the power station extension site behind retaining seawalls. These constraints were recommended to control water quality impacts to within acceptable levels, are also expected to control impacts to fisheries resources. Hence, no fisheries-specific mitigation measures are required during construction.

Impacts to fisheries resources and fishing operations during operation of the power station extension are predicted to be within environmentally acceptable levels in areas of importance to the fishery. Hence, no fisheries-specific mitigation measures are required during operation of the power station.

11.8 RESIDUAL IMPACT

Based on the value to the fishery of the areas discussed in the previous sections and the specified mitigation requirements the residual impact (ie remaining after mitigation) can be determined. Two residual impacts to fisheries resources and operations have been identified and are defined and evaluated below following the guidelines presented in Section 4.4.3 of the EIAO TM.

11.8.1 *Discharges from the Power Station Extension*

During operation of the power station extension under periods when electricity demand is high, both the gas-fired extension plus units of the existing coal-fired power station will be used. The result of this will be unavoidable additional discharges of heated water and residual free chlorine. The Evaluation of Impacts (*Section 11.6*) has highlighted that discharges of heated water are not expected to be of concern as the area of sea that exceeds the water quality objective (7.8 km^2) is 23 % smaller when the gas-fired extension and the existing coal-fired power station are used together than that produced solely by the existing power station. However, there will be an additional area of surface waters affected by residual free chlorine that extends 200m offshore from the western seawall of the planned extension. The effects of this discharge on fisheries resources, specifically fish fry or eggs that reside in the surface layer cannot be practically mitigated for and thus become a residual impact. However, as the concentration of residual free chlorine is low in this area (0.01 mg L^{-1} below field detectable levels), a value below which toxic effects have been demonstrated to occur for fish eggs, fry and adults, the severity of this residual impact is considered to be low.

11.8.2 *Fishing Ground Loss*

The identified residual impact occurring during the construction of the power station is the permanent loss of 22 ha of the Po Law Tsui Fishing Area. The Evaluation of Impacts section (*Section 11.6*) has identified that this loss will impact primarily fishermen from the Luk Chau home port resulting in a decrease of < 1 % of the annual catch. The loss of this part of the fishing ground, although potentially detrimental to some fishermen is unlikely to cause a noticeable reduction in fish catches. Although not implemented specifically to mitigate for the loss of fishing grounds, the provision of rubble mound seawalls on which more diverse and abundant ecological assemblages than present on the existing flat muddy seabed can colonise and grow, has the potential to provide habitat and shelter for juveniles or adults. However, as part of the seawall is located in an area affected by heated water and residual free chlorine (the "mixing zone" as described in *Section* 5.5.2) the ultimate effect of the structure in benefitting the fishery cannot be determined. The combination of the small area lost, the low dependency on the area by local fishermen and the potential environmental benefits of the seawall combine to reduce the magnitude of this residual impact to acceptable levels. It should be noted however, that permanent loss of fishing ground may be subject to claims for *ex gratia* allowances which are administered by the Planning Environment and Lands Bureau.

11.9 *EM&A REQUIREMENTS*

The dredging operations include constraints which act as appropriate mitigation measures to control environmental impacts to within acceptable levels. Actual impacts of construction activities will be monitored through impacts to water quality. Monitoring and audit activities designed to detect and mitigate any unacceptable impacts to water quality will serve to protect against unacceptable impacts to fisheries resources.

The water quality monitoring programme will provide management actions and supplemental mitigation measures to be employed should impacts arise, thereby ensuring the environmental acceptability of the project. As only minimal impacts to the fishery are predicted to occur, the development and implementation of a monitoring and audit programme specifically designed to assess the effects of the construction activities on commercial fisheries resources is not deemed necessary.

Impacts of operational activities will be monitored through on-site monitoring of water quality parameters (including chlorine and temperature) of the discharged cooling waters. Monitoring and audit activities designed to detect and mitigate any unacceptable impacts to water quality will serve to protect against unacceptable impacts to fisheries resources.

The discharge monitoring programme will provide management actions and supplemental mitigation measures to be employed should impacts arise, thereby ensuring the environmental acceptability of the project. As no impacts of concern to the fishery are predicted to occur, the development and implementation of a monitoring and audit programme specifically designed to assess the effects of operational activities on commercial fisheries resources is not deemed necessary.

11.10 *SUMMARY AND CONCLUSIONS*

Reviews of existing information on commercial fisheries resources and fishing operations located within the Study Area have been undertaken for this impact assessment. Information from a recent study on fishing operations in Hong Kong indicates that fisheries production values from these areas are highly variable within the Study Area.

Potential impacts to fisheries resources and fishing operations may arise from disturbances to benthic habitats on which the fisheries resources depend, or through changes to key water quality parameters, as a result of the following proposed reclamation for the Lamma Power Station Extension.

Permanent losses to fisheries production will only occur as a result of the construction of the reclamation. This will involve the loss of 22 ha (5.5%) of the Po Law Tsui Fishing Zone. The assessment identified habitat loss in the Po Law Tsui fishing zone as a residual impact. The combination of the small area affected and the low dependency on the area by local fishermen (**about 0.05% of catch value < 1 % of catch**) combine to reduce the magnitude of this residual impacts to acceptable levels. It should be noted, however, that permanent loss of fishing ground may be subject to claims for *ex gratia* allowances which are administered by the Planning Environment and Lands Bureau.

Temporary impacts to fisheries resources are predicted to occur through dispersion of suspended sediment. Potential impacts to fisheries resources and fishing operations during operation of the power station extension may arise as a result of the following activities:

- intake of cooling waters causing entrainment and subsequent mortality of fish eggs and larvae, or impingement of adult fish;
- discharge of temperature elevated cooling waters causing mortality of fish eggs, larvae and adult fisheries resources;
- discharge of residual free chlorine as a result of antifouling measures causing lethal or sublethal effects to fish eggs, larvae and adult fisheries resources; and
- discharge of temperature elevated cooling waters which may contribute to a red tide event.

Entrainment of fish eggs and larvae, and impingement of adult fish is predicted, in the worst case situation, to remain the same as that caused by the existing power station once the extension is in operation. This is a result of the shift of the majority of baseload generating capacity from the existing coal-fired plant to the gas-fired extension which uses less cooling water. Impacts to fish eggs, larvae and adults are, therefore, considered to be small and within environmentally acceptable levels.

The temperature of the waters surrounding the power station are predicted to be elevated to a lesser degree than they are at present as a result of cooling water discharges from the existing power station. This indicates that impacts to fisheries resources are predicted to be within environmentally acceptable levels and consequently expected to be small.

Residual free chlorine will be present in cooling water discharges arising from the operation of the power station extension. However, the maximum discharge concentration of chlorine is predicted to remain at the existing level of 0.3 mg l^{-1} which is below the existing license limit of 0.5 mg l^{-1}. Although toxic effects of chlorine have been demonstrated to occur in adult fish at levels less than 0.3 mg l^{-1} and the toxicity of chlorine is synergistically increased at higher temperatures, these impacts are not predicted to be of concern because chlorine concentrations in the water column are predicted to decrease rapidly with time and distance from the outfall and fish have been shown to avoid areas where chlorine can be detected above 0.035 mg l^{-1}. Furthermore fish eggs and larvae exhibit greater tolerance to residual chlorine and any impacts to these resources will be confined to the immediate vicinity of the outfall.

The additional discharge of residual free chlorine in close proximity to the power station was also identified as a residual impact. However, as the concentration of chlorine is low in this area (0.01 mg L^{-1} - below field detectable levels) and below the level at which toxic effects have been demonstrated to occur for fish eggs, fry and adult, the severity of this residual impact is considered to be low.

A red tide assessment conducted as part of this fisheries impact assessment has indicated that temperature elevated discharges are not thought to be the primary cause of red tides/harmful algal blooms. A combination of factors, including nitrate and phosphate levels, organic loading, the presence or absence of red tide cysts and temperature are thought to interact to cause red tide blooms. Conditions predicted to occur as a result of cooling water discharges from the power station extension are not indicative of suitable conditions for the initiation of a red tide/harmful algal bloom.

Fisheries impacts arising from the operation of the power station extension are predicted to be within environmentally acceptable limits and, hence, no fisheries specific mitigation measures are recommended. Monitoring and audit activities designed to detect and mitigate any unacceptable impacts to water quality will serve to protect against unacceptable impacts to fisheries resources.