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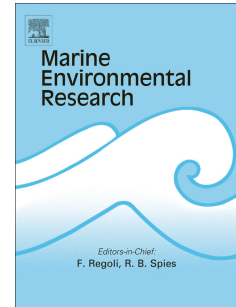
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Abstract

Marine organisms comprised about 70% of the total impinged materials by weight at water intake screens in the Kapar Power Station (KPS), Malaysia. The general groupings of 'fish', 'shrimp', 'crab', 'cephalopod' and 'others' contributed 26%(87 species), 65%(29), 2%(17), 2%(3) and 5%(42) of the total number of impinged organisms, respectively. In general, higher impingement occurred during spring tide, at nighttime and in shallow water. The glass perchlet, anchovies, ponyfishes, mojarra, catfishes, hairtail, scat and young croakers were the most vulnerable fishes. Vulnerable invertebrates included cephalopods, sea urchin, rockshells and jellyfishes, but penaeid shrimps were the most susceptible in terms of both mortality and body injury. Annually, KPS is estimated to kill 8.5×10^6 marine organisms (42 tons) by impingement. This amount, however, is minimal compared to commercial fishery harvests. Multispecies impingement at Malaysian power plants poses the problem of finding the best mitigation options for tropical situations.

1. Introduction

Once-through cooled (OTC) power plants extract massive quantities of seawater to cool down superheated steam in their condensers. A single large power plant can extract millions of cubic meters of cooling water daily before discharging much of that water back into the sea at temperatures much higher than before. Withdrawn seawater, debris, fish and other organisms are forcibly impinged against filter screens installed to prevent debris from entering the cooling system which could cause serious damage to equipment and even shut down of the power plant (Majewski and Miller, 1979; Ronafalvy et al., 2000). Fish striking or caught on the screen surface however suffer injury, asphyxiation or mortality. The fish impingement process is also influenced by environmental conditions and fish behavior, besides the plant operation. In contrast to impingement, entrainment is the process whereby fish eggs, larvae and small fishes of usually less than 50mm length pass through the screens but are trapped and killed off by high temperature and chlorine inside the cooling system (Vaughan, 1988; Turnpenny and Taylor, 2000).

Fish mortality induced by both impingement and entrainment has been the main environmental issue involving power plants. While entrainment mortality is usually very high, for instance, 132 million fish eggs and larvae or 23% of the total river ichthyoplankton at Wabash River Station, USA, clear adverse impacts on fish populations have been difficult to quantify (Lewis and Seegert, 2000). Impingement mortality although very variable may be in the order of tens of millions of fish annually (Haddingh and Jagger, 2002; Greenwood, 2007). In the UK, impinged fish losses at east coast power stations ranged from 0.22% of the commercial catches for cod to 180% for whiting (Turnpenny and Taylor, 2000). In contrast, 15 harvested fish stocks off the California and Atlantic coasts were estimated to be depressed by entrainment and impingement by less than 1% in 10 of 15 cases considered, between 1-3% in two cases, and between 20-80% in three cases (Newbold and

Iovanna, 2007). Both entrainment and impingement mortalities are generally directly proportional

55 to the extracted volume of cooling water (Henderson and Seaby, 2000; Greenwood, 2007). Based
1
2 on an estimated 50-75% total pumping capacity used annually by 45 large power stations in north
3
4 European waters, Henderson (2009) estimated a total of $3-5 \times 10^8$ fish and about 10^{14} fish eggs and
5
6 larvae killed annually by impingement and entrainment.
7

8
9 There are seven coastal OTC power plants in Malaysia, which were built relatively recently to
10
11 cater for the country's increasing demand for electricity. Environmental impacts of the siting and
12
13 operation of these power plants are unknown, but concern of high impingement and entrainment
14
15 mortality of marine organisms is not without basis since several of these electric power plants are
16
17 sited on or close to mangroves or tidal flats known to serve as nursery areas for marine fauna
18
19 (Chong, 2007). New power plants, including nuclear power, are being planned for the future to
20
21 cater for the country's fast growing population and economy. In fact, the proliferation of power
22
23 plants in the ASEAN region is imminent in the near future based on the International Energy
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25 Agency (IEA)'s 2009 World Energy Outlook forecast stating that the energy demand of the ten
26
27 ASEAN countries would expand by 76% for the period 2007-2030.
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34 Given the lack of knowledge on power plant impacts in tropical waters, the aim of this study
35
36 was to determine the biotic losses due to impingement at cooling water intakes in the Kapar Power
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38 Station (Malaysia), which is located at a coastal mudflat near to mangrove forests. This OTC
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40 power station extracts up to 6 million m^3 of sea water daily.
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46 **2. Material and methods**

47 48 49 50 51 *2.1 Study sites*

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56 Kapar Power Station (hereafter referred to as KPS) is a coal-, oil- and gas-fired thermal
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58 electricity generating station facing the Straits of Malacca. KPS (Lat $3^{\circ} 06' 47.02''$ N, Long 101°
59
60 $19' 06.89''$ E) is located 24 km north of Port Klang, Malaysia's largest port (Fig. 1). The power
61

Fig. 1

station is situated just north of the small Kapar River estuary in the state of Selangor. An extensive mudflat fronts the station to as far as a kilometer offshore, while mangrove forests (and mudflats) line the upper shore to the north and south of it. Much of the mangrove forests are however converted for agriculture and industrial development leaving only a narrow coastal strip of 0.5-1 km width. The study area experiences strong semidiurnal tides, and sea level rises and falls within a mean range of 4.2m and 1.4m with tidal velocities reaching 1.5 ms^{-1} and 0.4 ms^{-1} for spring and neap tide, respectively (Chong et al., 1996).

The power station currently generates 2420 MW of electricity to help support the power demand of the nation's most populated region, the Klang Valley. KPS has been operating since 1987 when it first started with two intake points for cooling water extraction (Phase I), followed by two additional intake points at its second phase of operation, and finally in 1991 two further intake points were added (Phase III). The six intake points have a combined water extraction rate of $71.4 \text{ m}^3 \text{ s}^{-1}$.

The circulating water system used at KPS is an open system, whereby seawater enters the circulating water pump (CWP) bays through an intake structure. Primary screens (vertical bar screens) prevent large debris from entering the CWP bays, furthermore any debris that passes through them is blocked by a rotary drum screen. Debris such as fish, leaves, garbage, etc. caught on the drum screen (10-mm mesh) are washed down by high pressure seawater jets, before flowing down along steel chutes and finally into steel trash baskets.

The heated once-through cooling water is returned via two discharge outlets, one at the southern end of the station and the other at its northern end. Measurements taken along a 4 km-transect from the south outfall towards sea recorded water temperatures of $32 - 29^\circ\text{C}$ and salinities of 22-28 ppt, although thermal plumes moving up the narrow Kapar estuary during flood tide could yield temperatures of up to 36°C (Anton, 1990). The heat however quickly dissipates beyond 0.5 km from the outfall.

Unit 1 (Phase I) and Unit 6 (Phase III) of the intake points at KPS were chosen as the sampling locations for impinged marine organisms. Due to siltation, Unit 1, located approximately 0.75 km

just off the outer edge of the coastal mudflat, is sometimes exposed during extreme low tide, as the average water depth is now less than 5 m, whereas originally it was 7 m. Unit 6 is located another 0.44 km farther out into deeper water.

2.2 *Sampling design*

The tidal height at the study site was determined from the local Tide Table (Royal Malaysian Navy, 2004) from May 26 through to July 19, 2004, to choose the appropriate sampling time. Fish and invertebrates were sampled from the steel trash basket of each intake unit at approximately 12-hourly sampling intervals for two consecutive days (thus, two-day and two-night samples) each week. The exact sampling times ranged from 9.7 to 12.8 hours. Samples were collected for four consecutive weeks covering 1st quarter, full moon, 3rd quarter and new moon phases. Due to the station's administrative constraints, samplings at Unit 6 were carried out one month after sampling Unit 1.

For standardization purpose, the 12-hour period from 0800 hr to 2000 hr was designated as "day" sampling and from 2000 hr to 0800 hr the next morning was designated as "night" sampling.

The entire sample contained a mix of marine organisms and solid wastes. Organisms and inert debris were separated and weighed on site. The latter was recorded qualitatively before discarding. Collected organisms were taken either entirely or subsampled (50%) if the quantity was large. The samples were then preserved in 10% formaldehyde in large plastic bins and taken back to the laboratory for further examination.

2.3 *Laboratory analysis*

In the laboratory, samples preserved for at least a week were first washed in running water for several hours before they were transferred into 70% alcohol prior to examination. Samples were sorted and identified to species level whenever possible using available taxonomic keys. After

135 identification, total number of individuals and total weight (g) of each species collected at a
particular date and time were recorded. Qualitative assessment of body condition of the specimens
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2 in term of damage condition was also noted.
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7 2.4 Data analysis 8

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11 Due to the many and varied types of marine organisms obtained, they were grouped into five
12 general faunal categories: 'fish', 'shrimp', 'crab', 'cephalopod' and 'others'. Shrimp comprised
13 decapod and mantis shrimps. Data on the abundance and biomass of species impinged were
14 calculated in terms of catch per unit effort (CPUE), i.e. number and weight of individuals per 12
15 hour-sampling.
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24 Two-way analysis of variance (ANOVA) was performed using the STATISTICA software on
25 \log_{10} - transformed CPUE of each faunal category. The factors tested were tide (NM- new moon,
26 Q1- 1st quarter, FM- full moon, Q3- 3rd quarter) and diel effect (day, night).
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34 3. Results 35

36 3.1. Proportion of impinged living organisms 37 38 39 40 41 42 43

44 During the screening process, not only marine organisms were separated out of the intake
45 cooling water, but also inert materials or solid debris such as leaves, twigs and propagules, empty
46 mollusc shells, plastic bags and bottles, rag fabrics, fish nettings and other garbage. The proportion
47 of marine organisms to inert materials collected at Unit 1 and Unit 6 was quite similar, with an
48 average ratio of about 2:1. The entire collection of marine organisms at Unit 1 (16 12-hr sampling
49 periods) totaled 43,845 specimens weighing 156.67 kg, whereas for the deeper water Unit 6 (16 12-
50 hr sampling periods) 18,324 specimens weighing 150.15 kg were collected. The mean impingement
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rate at Unit 1 in terms of number and weight per 12 hr (CPUE) were 2741 (\pm 3361) and 9.8 kg (\pm 10.6), and at Unit 6 these were 1145 (\pm 610) and 9.4 kg (\pm 7.8).

The proportion (%) of marine organisms to inert materials collected during nighttime was 72.34:27.66 by weight as compared to 62.45:37.55 during day. CPUE of total impinged marine organisms at night (mean=3864) was always higher than day (1617) ($P=0.003$), with a mean ratio of night to day impingement of 3.1 (\pm 1.8) at Unit 1. At the deeper water Unit 6, night (1205) and day (1086) CPUE were about equal with no significant difference ($P=0.60$); mean ratio of night to day impingement was 1.35 ± 0.93 .

In term of total impingement by weight (kg/12hr), the results were similar as with CPUE (numbers); 13.18 and 6.41 for Unit 1 and 8.05 and 10.72 for Unit 6, during night and day respectively. Mean weight ratio of night to day impingement was $3.29 (\pm 3.15)$ and $1.13 (\pm 0.66)$ for Unit 1 and 6, respectively. The rate of impingement of inert material appeared to be similar during night and day at Unit 1, but at Unit 6 the inert material collected during night was half as much as during day.

The proportion of inert material to marine organisms however increased from neap to spring tide reflecting the stronger tidal currents during spring tide that moved the inert materials into the water intakes. At the same time, impingement of marine organisms significantly increased during spring tide ($P<0.05$). At Unit 1, the mean total impinged organisms ranked and statistically tested (5% significance level) for moon phase are as follows: FM (7138) > NM (2662) > Q1 (628) \approx Q3 (534). At Unit 6, these were FM (1873) \approx Q3 (1031) \approx NM (1020) \approx Q1 (658); only FM was significantly greater than Q1 ($P<0.05$).

3.2. *Species of impinged marine organisms*

Appendix A lists the 178 species of marine organisms impinged on the water intake screens of KPS during the study. 114 species are listed as economically important species contributing to 90%

and 74% of the total impinged organisms by number of individuals and weight, respectively. The marine organisms comprised 87 species of fishes, 22 species of decapod shrimps, 7 species of stomatopods (mantis shrimps), 17 species of crabs, 3 species of cephalopods, and 42 species of other organisms comprising scyphozoan jellyfish (5), polychaetes (6), gastropods (6), bivalves (3), horse-shoe crabs (2), anomurans (3), isopods (1), sea urchins (1), sea cucumbers (14) and brittle star (1).

Anchovies (*Thryssa kammalensis*, *Coilia dussumieri*), croaker (*Dendrophysa russelii*), ponyfishes (*Leiognathus splendens*, *Secutor insidiator*), mojarra (*Gerres erythrourus*), catfishes (*Arius sagor*, *A. maculatus*), hairtail (*Lepturacanthus savala*) and scat (*Scatophagus argus*) were among the most frequently impinged fish (> 80% occurrence). Among invertebrates, penaeid shrimps (*Penaeus merguensis*, *Metapenaeus* spp., *Parapenaeopsis* spp.), small swimming crabs (*Charybdis* spp.), the leaf porter crab (*Neodorippe callida*), sea urchin (*Salmacis dussumieri*) and the spineless cuttlefish (*Sepiella inermis*) were the most frequently impinged. Rockshells (*Thais* spp.), which are common predators of mudflat bivalves, were also frequently impinged (91%). The large but slow-moving bottom dweller of the mudflat, the horse-shoe crab (*Carcinoscopius rotundicauda*), appeared quite vulnerable to impingement (72%).

From the total of 62,169 individuals of impinged marine organisms, the percentage compositions of the different groups of marine organisms are as follows: fish (26%), shrimp (65%), crab (2%), cephalopod (2%) and others (5%). Based on abundance, the two highest impinged species were the penaeid shrimp, *Metapenaeus affinis*, and the glass perchlet, *Ambassis gymnocephalus*. Two other penaeid shrimps ranked third (*Penaeus merguensis*) and fourth (*M. brevicornis*) highest. The top 20 species comprised seven decapod shrimps, eight fishes, two cephalopods, one sea urchin, one gastropod and one edible jellyfish (*Lobonema smithii*). All had impingement frequency exceeding 66% except the latter (19%) indicating the infrequent but large swarms of jellyfish when present.

3.3. Species richness

215 Each collected sample contained between 31 and 85 species, which comprised 8 to 41 fish
 1 species and 13 to 41 invertebrate species (Fig. 2). For both fish and invertebrates, the relationship
 2
 3 between species number and number of samples formed an increasing trend approaching but not
 4
 5 reaching the asymptote (see Fig. 2). Both asymptotes for fish and invertebrate appear close to 100
 6
 7 species.
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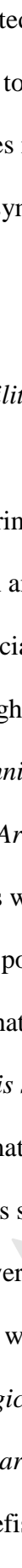


Fig. 2

3.4. Vulnerability in relation to diel and tidal changes

19 Fishes, shrimps and cephalopods showed higher impingement rates during night than day
 20 (P<0.05). Fish and shrimps in particular were also more heavily impinged during spring tide than
 21
 22 neap tide, especially during full moon (P<0.05) (Fig. 3). Most of the fish species that were
 23
 24 impinged at higher numbers during spring tide and nighttime were croakers (e.g. *Johnius*
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 29 *belangerii*, *Johnius borneensis*, *Dendrophyssa russelii*, *Nibea soldado* and sciaenid juveniles),
 30
 31 catfishes (e.g. *Arius sagor* and *Arius maculatus*) and the scat (*Scatophagus argus*). However, a few
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 33 species such as white pomfret (*Pampus argenteus*), anchovy (*Thryssa hamiltonii*), carangid (*Alepes*
 34
 35
 36 *djeddaba*) and ponyfish (*Leiognathus splendens*) were more impinged during night neap tides.
 37



Fig. 3

38 Shrimps that were more susceptible to impingement at night during spring tide included
 39
 40 *Parapenaeopsis sculptilis*, *Metapenaeus ensis*, *Penaeus merguensis* and *Palaemon styliferus*.
 41
 42 However, stomatopods were more impinged during spring tide with no diel effect. Small and
 43
 44 weaker shrimps such as sergestid (*Acetes* sp.), hippolytid (*Mimocaris* sp.) and postlarvae of
 45
 46 stomatopods were equally vulnerable during both spring and neap tides.
 47
 48
 49

50 Crabs that were more impinged during spring tide were mainly swimming crabs such as
 51
 52 *Portunus pelagicus* and *Charybdis japonica*. In contrast, species such as *Hyastenus diacanthus* and
 53
 54 *Myomenippe hardwickii* appeared vulnerable during daytime irrespective of tidal conditions. The
 55
 56 spineless cuttlefish, *Sepiella inermis*, tended to be more impinged at night irrespective of tide, while
 57
 58 an octopus (*Octopus* sp.) was subject to higher impingement during spring tide with no diel effect.
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 60
 61

The total of 306.82 kg of impinged organisms comprised of the following: fish (40%), shrimp (23%), crab (2%), cephalopod (6%) and others (29%). In term of biomass, the highest was the catfish *A. sagor*, followed by the edible jellyfish (*Lobonema smithii*), the horse-shoe crab (*T. gigas*), the scat and spineless cuttlefish. In contrast to abundance, none of the biomass of shrimp species was ranked in the top five. Fish, shrimps and cephalopods also showed higher impinged biomass during night than day. Impingement rates were also higher during spring tide (particularly full moon) for fish and shrimps (Table 1).

3.5. Size of Impinged Marine Organisms

The average sizes of fish, shrimp, crab and cephalopod were 7.51 g, 1.77 g, 5.04 g and 14.83 g, respectively (see Table 1). Thus, the majority of impinged organisms were small juveniles.

Table 1

3.6. Assessment of injury caused by impingement

Among the five broad categories, shrimps suffered the highest injury by weight (Fig. 4), with damaged ones constituting 56% of the total shrimp biomass. Visible injuries consisted of crushed carapace and exoskeleton, eye injury and broken appendages. Crabs suffered lower damage (16%) as did cephalopods (0.2%). Some 98% of impinged fish had little signs of external body damage. Observed injuries were in the form of damaged fins and skin, scale loss and bruised bodies. Jellyfish (scyphozoan medusa) were the most damaged amongst the 'Others' category, suffering about 17% damage due to broken body parts.

Fig. 4

3.7. Estimated annual loss by impingement

In this study, 100% mortality is assumed for all impinged marine organisms, as there is no recovery system installed at KPS. Estimation of annual impingement was made based on the assumption of worst-case scenario, that is, cooling water was continuously extracted at all six water

intake points without any interruption for 365 days. Hence, the extrapolated annual loss of marine organisms at KPS based on our study of 32 consecutive biweekly samplings over two months at all intake points was 8.5×10^6 individuals or 42 tons of mostly juvenile marine organisms (Table 2).

Table 2

4. Discussion

The estimated annual fish impingement of 2.2×10^6 (16.54 tons) at KPS is lower than power stations of comparable size, for example, at the 2400 MW Longannet Power Station on the Forth estuary, UK, where 1.25×10^7 (74 tons) and 4.41×10^7 fish (184.4 tons) were impinged in 1999 and 2000 respectively (Greenwood, 2008), but closer to the Pembroke power station at Daugleddau estuary, UK, where an estimated 1.6×10^6 fish were impinged (Turnpenny et al., 1997). The Malaysian estimate also falls within the fish impingement mortality of $79 \times 10^3 - 9.6 \times 10^6$ (13 – 18.6 tons) reported at Calvert Cliffs Nuclear Power Plant, USA (Ringger, 2000). However, fish impingement mortality at power stations varies markedly, seasonally and annually (Table 3), being affected by such factors as fish aggregation, latitude, habitat, tidal action and intake flow (see Hocutt et al., 1980; Henderson, 1989; Greenwood, 2007).

It is not known how density-dependent (or density-independent) mortality operates and thus modifies fish impingement, but competing impingement caused by other marine biota may be important. Impingement in tropical waters may be characteristically species-rich as in KPS where 178 species of marine biota were recorded over a 2-month period. In fact, a major portion of the estimated total biota impinged on KPS screens (8.5×10^6) consisted of invertebrates. Impinged fish species, which totaled 87 species, represent 43.5% of the 200 recorded fish species in Klang Strait (Chong et al., 2005). The total (cumulative) number of impinged fish species recorded in just the first month of study (sixteen 12-hourly samples) was 68. In contrast, impingements of more than 68 fish species in temperate waters are cumulative species number recorded from one to 21 years of study (Table 3). Seven British power stations had mean numbers that ranged from 18.5 – 35 species (Henderson, 1989). In sub-tropical waters, for e.g. Taiwan, the cumulative fish species

Table 3

295 number (196) over nearly seven years appears high, but the numbers that were impinged in a month
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(4 – 48 species) were nearly the same as in KPS for a 12-hour sample.

1
2 The maximum species number (MSN) at KPS site is close to 200 species or approximately 100
3
4 each for fish and invertebrates (see Fig. 2). This number is larger than the MSN values reported for
5
6 seven temperate power plant sites that ranged from 51 - 80 fish species (Henderson, 1989), but
7
8 close to the sub-tropical MSN value of 196 species reported in Taiwan waters (Liao et al., 2004).
9
10 Henderson (1989) derived an empirical linear relationship ($S = - 7.85 L + 478.8$) for species
11
12 numbers (S) against latitude (L, in degrees) which fitted very well the data from temperate power
13
14 plants in marine waters (species number also declines with declining salinity), and proposed the rule
15
16 of a maximum of 80 species that any UK sites may hold. Including the tropical (KPS = 3 degrees)
17
18 and sub-tropical (Taiwan = 25 degrees) MSN values in the analysis may imply a more general
19
20 parabolic relationship from the northern to southern hemisphere. However, more research in
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22 tropical and sub-tropical sites is needed to test this interesting relationship.
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29 Fish impingement in temperate waters also indicates the dominance of a few species. In most
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31 cases, two species combined would have contributed more than 60% of the total number of fish
32
33 impinged (see Table 3). In KPS, the most abundant species of fish (*Ambassis gymnocephalus*) and
34
35 shrimp (*Metapenaeus affinis*) respectively contributed to only 5% and 10% of the total number of
36
37 impinged organisms. Thus, the lower proportion of fish impinged at KPS screens results from
38
39 competing impingement due to the high diversity of other marine organisms in tropical waters.
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41
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43 Shrimps are the most susceptible biota at KPS; impingement kills 2.5 times more shrimps (5.55
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45 $\times 10^6$) than fish. Fourteen of 17 ever-recorded species of penaeid shrimps in Klang Strait (Chong
46
47 et al., 2005) were amongst those impinged. All three palaemonid shrimp species ever reported in
48
49 the area were also impinged. The present study also indicates that fish and shrimps are more
50
51 vulnerable to impingement in shallow water (< 5m) since Unit 1 had 24% higher impingement than
52
53 Unit 6 which is located further offshore (>7m depth). These results are not unexpected since the
54
55 juveniles of many marine fishes use Klang mangrove and coastal mudflats as feeding areas, while
56
57 penaeid shrimps depend on them for nursery areas (Newell et al., 1995; Chong et al., 2005).
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1 protection from larger predators (Blaber, 2000; Chong, 2007). As the mudflat becomes inundated
 2 with seawater during high spring tide, more feeding or refuge ground becomes available, thus
 3
 4 attracting more marine organisms into it and into the adjacent mangrove forest. This would explain
 5
 6 why higher numbers of juvenile fishes, shrimps and others were impinged at KPS screens during
 7
 8 spring tide. In general, tidal changes have a strong influence on the impingement rate of marine
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 10 organisms at the cooling water intakes, due to the inability of these organisms to quickly swim
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 12 away from the combination of strong tidal flow and water suction, although some might just
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 14 passively drift into them.
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19 Penaeid shrimps, particularly *M. brevicorni*, *M. affinis* and *Pa. sculptilis*, are subject to higher
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 21 impingement during nighttime. Such species become active at night when in the day they burrow
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 23 under sediment to avoid predators, a behavior that explains why trawl catches of shrimps were
 24
 25 higher during night than day (Low and Chong, 1999; Chong, 2007). Like shrimp, fish
 26
 27 vulnerability also depends on behavior, tidal and diel activity as well as their swimming agility
 28
 29 (Krumme et al., 2004). Demersal fish species such as young croakers, catfish and scat which feed
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 31 on small shrimps (Then, 2008) are also more vulnerable during night and spring tide, while weak
 32
 33 pelagic swimmers such as pomfret, ponyfish and anchovy are more vulnerable during night and
 34
 35 neap tide. It is not clearly understood why, only in shallow water, night impingement was 3 times
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 37 higher than day impingement, while full moon impingement was 1.8 – 2.7 times higher than new
 38
 39 moon impingement. In a few other species, there were no apparent effects of light (e.g. octopus,
 40
 41 horseshoe crab and stomatopods); higher impingement occurred at night (cuttlefish) or day (some
 42
 43 non-swimming crabs) irrespective of tide; and impingement was equal at neap and spring tide
 44
 45 (sergestid and hippolytid shrimps). Heavy debris loads such as plastic bags and mangrove leaves
 46
 47 could reduce an organism's ability to avoid impingement, as for example, eelgrass or algae that
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 49 were impinged on traveling screens reportedly entangled other organisms (Duke Energy, 2001). It
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 51 appears that the severity of impingement in tropical waters is dependent on the interaction effects of
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 53 environmental factors like tide, light, water depth and inert materials on the one hand, and
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organisms' behavior, activity pattern and swimming ability on the other. More studies are required

350 to elucidate these and other factors.

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2 Consistent with the mangrove and mudflat's function as nursery or feeding area, fish, shrimps
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4 and most other marine organisms impinged at KPS were predominantly juveniles, which are the
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6 most vulnerable and weakest swimmers. This means that the siting of the power plant itself would
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8 significantly influence the impingement rate of marine biota. Hence, its location on the mudflat
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10 area as well as near to mangroves is deemed not suitable and expected to cause higher impingement
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1255 as compared to a location farther out into the sea, or away from any of these critical habitats. The
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14 estimated total annual impingement at KPS of 42 tons represents only 0.1% of the annual marine
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16 landings of 44,800 tons for the combined districts of Port Klang and Kuala Selangor (Selangor State
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18 Fisheries Statistics, 2002). Nevertheless, the impingement mortality applies to young juveniles
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20 (see Table 1) and if there was no power plant, the removed organisms could translate into larger
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22 harvestable adults. Due to the lack of information on fish population parameters, the present study
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2460 did not derive an equivalent adult loss (Turnpenny, 1988) or assess population level impacts using
25
26 age-structured population models (e.g. Newbold and Iovanna, 2007). These types of analysis as
27
28 conducted in temperate waters indicate that in many cases the equivalent adult losses or impact on
29
30 fish populations due to impingement at single power plant are generally minimal in comparison to
31
32 fishery landings or by-catches (Turnpenny and Coughlan, 1992; Turnpenny and Taylor, 2000;
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34 Newbold and Iovanna, 2007; Greenwood, 2008), but severe for a few cases (Newbold and Iovanna,
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365 2007). However, the collective effect of several power plants in the same region, as for instance in
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38 northern European waters, can be colossal: 17 power stations in the southern North Sea are
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40 estimated to kill sole and herring equivalent to about 50% of Britain's commercial landings for the
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42 region (see Henderson, 2009).
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53 The severity of the impingement and entrainment (I&E) problem is nevertheless strong enough
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55 to trigger stringent law enforcement in most temperate countries where power plants are common.
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57 Monitoring studies are mandatory and intensively carried out to assess impacts even though
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59 mitigation measures are implemented in many power plants. For example, in the USA and UK,
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legislation covering power plant operations requires that the design, location, construction, and capacity of intake structures reflect the best available technology for minimizing environmental impact, which is an attempt to deal with the problems of I&E. In Malaysia, although the Environmental Quality Act, 1974, provides for similar considerations in an EIA prior to building the power plant, I&E effects are not considered a monitoring requirement. Because of this, the long term impacts of power plants due to I&E have been largely unknown or ignored. While it may become mandatory for plant managers to institute mitigation measures and monitoring at some point in the future, it is incumbent upon them to do so now, and to fulfill a CSR obligation to protect the environment. The benefits of monitoring are enormous benefiting both industrial and public interests (Henderson et al., 2007). Several studies by Henderson and co-workers (e.g. Henderson, 1989; Henderson et al., 1992) have shown how potentially useful power plant catches can be utilized to advance scientific knowledge on carrying capacity, niche occupation and trophic structure, and in the process, to give good advice pertaining to power plant siting and operations.

In conclusion, this study showed that total organism mortality caused by impingement on water-cooling screens at KPS is substantial, although the juvenile biomass removed by impingement is low in comparison to fisheries landings. In contrast to impingement dominated by a few main fish species in temperate waters, multispecies impingement occurs at KPS with implication on mitigation options. Continuous impingement monitoring at power plants in Malaysia is strongly advised as are further studies on the subject and the entrainment issue, which was not covered in the present study. The I&E problem is very relevant to the current issue of shrimp stock depletion due to overfishing and loss of nursery habitats whereby the state suffered 47% mangrove loss from 1980-2000 (Chong, 2006). Impingement further kills 5.5 million juvenile shrimps, while entrainment would remove a portion of the estimated 65 billion shrimp larvae recruited into Klang Strait annually (Chong et al., 1996). The number and siting of future power plants should be critically evaluated; power plants should never be sited near mangrove or on the mudflat where the larvae and juveniles of marine organisms abound all year round.

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Table 1.

Total weight and size of impinged organisms by faunal group sampled at 12-hourly intervals following moon phases and diel cycle,

Kapar Power Station, Malaysia. Q1=first quarter, FM=full moon, Q3=third quarter, NM=new moon; D=day time, N=night time.

Date	Sampling information				Weight (g per 12 hr)						Average body weight (g)				
	Sample	Intake Unit	Tide	Diel	Fish	Shrimps	Crabs	Cephalopods	Others	Total	Fish	Shrimps	Crabs	Cephalopods	Others
5/26/2004	S1	U1	Q1	D	755	283	40	57	562	1695	5.03	0.72	4.02	2.85	19.68
5/27/2004	S2	U1	Q1	N	2119	748	14	541	1176	4599	4.42	2.01	1.54	14.93	39.14
5/27/2004	S3	U1	Q1	D	177	5	12	32	35	261	3.61	0.12	1.03	1.97	1.65
5/28/2004	S4	U1	Q1	N	1450	393	111	720	200	2874	3.24	1.59	12.26	14.53	2.11
6/3/2004	S5	U1	FM	D	7444	2969	81	49	5521	16064	13.79	1.70	4.73	22.97	69.95
6/4/2004	S6	U1	FM	N	15102	12902	76	271	1940	30291	10.22	1.67	2.50	20.46	32.00
6/4/2004	S7	U1	FM	D	7995	6269	8	70	1767	16108	14.46	1.37	1.89	16.66	42.35
6/5/2004	S8	U1	FM	N	15044	18997	92	212	2260	36605	11.67	1.84	4.20	26.59	51.59
6/10/2004	S9	U1	Q3	D	925	43	22	135	1104	2230	8.05	0.77	2.73	16.64	47.51
6/11/2004	S10	U1	Q3	N	3045	526	17	620	815	5024	5.42	1.27	1.30	28.60	34.45
6/11/2004	S11	U1	Q3	D	698	71	119	118	201	1207	6.54	1.08	6.74	3.68	10.22
6/12/2004	S12	U1	Q3	N	1454	169	25	352	1043	3043	4.15	0.69	2.53	15.54	50.49
6/18/2004	S13	U1	NM	D	3214	2373	157	807	2081	8633	3.83	1.44	3.18	13.87	49.09

6/19/2004	S14	U1	NM	N	3276	5706	119	664	856	10622	6.89	1.93	2.67	41.79	26.94
6/19/2004	S15	U1	NM	D	2722	1594	131	401	231	5078	6.87	1.50	4.02	17.84	7.78
6/20/2004	S16	U1	NM	N	5124	4811	148	875	1383	12341	7.35	2.31	2.77	21.49	23.20
6/25/2004	S17	U6	Q1	D	1835	407	788	472	762	4263	25.48	2.19	9.60	26.23	21.17
6/26/2004	S18	U6	Q1	N	4526	329	991	2305	1679	9831	11.24	2.64	6.39	8.12	7.38
6/26/2004	S19	U6	Q1	D	606	764	99	430	4083	5983	12.91	2.05	4.42	7.26	47.59
6/27/2004	S20	U6	Q1	N	1187	219	185	1218	2227	5037	8.08	1.58	8.72	11.89	50.11
7/2/2004	S21	U6	FM	D	4454	1580	550	1548	3188	11319	6.67	1.77	6.25	24.96	30.66
7/3/2004	S22	U6	FM	N	8336	2611	216	1312	1614	14089	5.48	2.47	3.37	22.48	14.06
7/3/2004	S23	U6	FM	D	3904	1820	289	647	3079	9740	8.42	1.99	3.69	13.28	31.60
7/4/2004	S24	U6	FM	N	5851	1329	128	1217	1935	10461	8.91	3.04	3.94	26.41	22.91
4/9/2004	S25	U6	Q3	D	2495	950	287	260	1107	5099	3.85	1.67	4.12	10.88	6.46
4/10/2004	S26	U6	Q3	N	1874	576	35	648	1619	4753	4.42	1.58	1.55	20.31	11.50
4/10/2004	S27	U6	Q3	D	468	157	12	239	2307	3182	2.34	1.20	2.74	15.70	18.64
7/11/2003	S28	U6	Q3	N	2739	247	37	145	2656	5824	2.99	1.80	2.44	6.45	28.87
7/17/2004	S29	U6	NM	D	4073	1070	271	961	3544	9919	8.68	2.31	6.28	15.30	19.42
7/18/2004	S30	U6	NM	N	3893	715	108	496	807	6018	7.96	2.26	10.48	30.03	5.14
7/18/2004	S31	U6	NM	D	165	473	261	198	35138	36236	4.10	1.88	14.42	49.26	44.07
7/19/2004	S32	U6	NM	N	3873	475	107	808	3130	8393	9.74	2.28	3.58	18.92	38.30
Mean:					3776	2237	173	588	2814	9588	7.51	1.77	5.04	14.83	28.22
SE:					3685	4012	221	510	6026	9140	0.80	0.11	0.57	1.81	3.06

Table 2.

Estimated annual loss of marine organisms and species most vulnerable to impingement at Kapar Power Station, Malaysia.

Group	Species / Taxa	Frequency	Projected annual loss (abundance)	Percentage of total abundance	Projected annual loss (kg)	Percentage of total biomass
FISH (87 species)	<i>Ambassis gymnocephalus</i>	25/32	421,967	4.96	1,045	2.49
Total abundance loss = 2,202,182 individuals or 25.9% of total annual impingement	<i>Thryssa kammalensis</i>	32/32	259,921	0.29	662	1.58
	<i>Leiognathus splendens</i>	29/32	245,701	2.89	617	1.47
	<i>Arius sagor</i>	28/32	166,918	1.96	5,257	12.52
	<i>Scatophagus argus</i>	28/32	143,272	1.67	2,068	4.92
	<i>Gerres erythrourus</i>	28/32	112,699	1.32	437	1.04
Total biomass loss = 16,537 kg or 39.4% of total annual impingement	<i>Dendophysa russelii</i>	24/32	74,184	0.87	402	0.96
	<i>Arius maculatus</i>	24/32	53,854	0.63	300	0.72
	<i>Liza subviridis</i>	24/32	40,198	0.47	759	1.81
	<i>Pampus argenteus</i>	19/32	38,751	0.46	114	0.27
	<i>Lepturacanthus savala</i>	27/32	37,742	0.44	186	0.44
	<i>Pomadasys kaakan</i>	14/32	33,951	0.40	207	0.49
	<i>Herklotsichthys punctatus</i>	13/32	28,755	0.34	31	0.07
	<i>Anodontostoma chacunda</i>	20/32	27,542	0.32	63	0.15
SHRIMPS (22 species)	<i>Metapenaeus affinis</i>	31/32	846,711	9.95	1,437	3.42
Total abundance loss = 5,492,657 or 64.5% of total annual impingement	<i>Penaeus merguensis</i>	28/32	409,731	4.82	1,425	3.39
	<i>Metapenaeus brevicornis</i>	31/32	324,659	3.82	583	1.39
	<i>Parapenaeopsis sculptilis</i>	28/32	89,026	1.05	223	0.53
	<i>Acetes</i> sp.	24/32	69,815	1.05	21	0.05
Total biomass loss = 9,658 kg or 23.0% of total annual impingement	<i>Palaemon styliferus</i>	21/32	55,173	0.64	75	0.18
	<i>Parapenaeopsis maxillipedo</i>	22/32	49,377	0.58	53	0.13
	<i>Metapenaeus ensis</i>	25/32	49,315	0.58	107	0.25
STOMATOPODS (7 species)	<i>Oratosquilla interrupta</i>	12/32	6,858	0.08	48	0.11
Total abundance loss = 53,655 or 0.6% of total annual impingement	<i>Cloridopsis scorpio</i>	7/32	3,856	0.05	19	0.05
	<i>Clorida</i> sp.	7/32	3,064	0.04	10	0.02
	<i>Miyakea nepa</i>	4/32	2,682	0.03	14	0.03
	<i>Dictyosquilla foveolata</i>	3/32	1,644	0.02	12	0.03

Group	Species / Taxa	Frequency	Projected annual loss (abundance)	Percentage of total abundance	Projected annual loss (kg)	Percentage of total biomass
Total biomass loss = 139 kg or 0.3% of total annual impingement	<i>Oratosquilla perpersa</i>	4/32	1,407	0.02	13	0.03
	CRABS (17 species)					
Total abundance loss = 150,426 or 1.8% of total annual impingement	<i>Charybdis japonica</i>	29/32	46,877	0.55	102	0.24
	<i>Neodorippe callida</i>	28/32	34,319	0.40	26	0.06
	<i>Myomenippe hardwicki</i>	14/32	16,338	0.19	202	0.48
	<i>Matuta planipes</i>	17/32	15,761	0.19	27	0.06
	<i>Doclea ovis</i>	17/32	9,559	0.11	22	0.05
	<i>Portunus pelagicus</i>	13/32	3,722	0.04	40	0.09
	<i>Charybdis anisodon</i>	6/32	2,746	0.03	69	0.16
Total biomass loss = 758 kg or 1.8% of total annual impingement	<i>Scylla paramamosain</i>	4/32	825	0.00	64	0.15
	CEPHALOPODS (3 species)					
	<i>Sepiella inermis</i>	30/32	108,201	1.27	1,944	4.63
Total abundance loss = 173,694 or 2.0% of total annual impingement	<i>Loligo</i> sp.	24/32	53,463	0.63	126	0.30
	<i>Octopus</i> sp.	22/32	12,096	0.14	502	1.20
Total biomass loss = 2,577 kg or 6.1% of total annual impingement	OTHERS (42 species)					
	<i>Salmacis dussumieri</i>	30/32	130,227	1.53	605	1.44
Total abundance loss = 436,769 or 5.1% of total annual impingement	<i>Lobonema smithii</i>	6/32	100,400	1.18	3,583	8.53
	<i>Thais tissoti</i>	29/32	51,445	0.60	84	0.20
	<i>Carcinoscorpius rotundicauda</i>	23/32	22,178	0.26	1,804	2.30
	Sea cucumber E	16/32	19,317	0.22	62	0.15
	<i>Perna viridis</i>	28/32	17,599	0.19	101	0.24
	<i>Natica maculosa</i>	16/32	16,176	0.19	34	0.08
Total biomass loss = 12,326 kg or 29.4% of total annual impingement	Ophiuroidea	2/32	16,002	0.19	5	0.01

Total annual impingement = 8,509,382 individuals or 41,996 kg

Table 3. List of total species number, major species and estimated annual impingement of fish in selected power stations of the world. Invertebrates (in parentheses) are included where information is available.

Power Plant	Location	Capacity (MW)	Year (period)	Numbers Impinged	Estimated Annual Impingement	No. of Species	Common name of main species	%	Source	
USA										
1	Comanche Peak	Caddo Lake, Texas	2300	1993-94 (1 yr)		262,498	13	Threadfin shad Bluegill sunfish	96 2	Spicer et al. (2000)
2	Quad Cities	Mississippi River, Illinois/Iowa	1630	1984-94		232,000 - 2,989,000		Gizzard shad Freshwater drum	66 21	LaJeone et al. (2000)
3	Chalk Point	Patuxent River, Maryland	2423	1976-1977		4,316,456		Atlantic menhaden Spot (Blue crab)	31 15 45	Richkus et al. (2000)
4	Davies-Besse	Lake Erie, Oak Harbor, Ohio	889	1977 (4 mo)	1936		15	Gizzard shad Freshwater drum White crappies	45 12 12	Reuter (1978)
5	Cayuga Wabash	Wabash River, Indiana Wabash River, Indiana	1075 930	1987-88 (6 mo)	1036 936		14	Gizzard shad Channel catfish Minnows	59 32	Lewis & Seggert (2000)
7	Oak Creek	Lake Michigan, Wisconsin	1211	1975-76		2,754,000		Alewife Rainbow smelt	78 21	Michaud (2000)
8	Presque Isle	Lake Superior, Wisconsin	617	1975-76	4,762	4762?	21	Rainbow smelt Burbot	87 4	Michaud (2000)
9	Calvert Cliffs	Chesapeake Bay, Maryland	1700	1975-1995 (21 yr)		79,000 - 9,600,000 (mean=	73 (20-51 /yr)	5 main species (including Bay anchovy &	>90	Ringger (2000)

UK & EUROPE					=1,300,000		hogchoker)		
10	Longganet	Forth estuary, Scotland	2400	1999-2000 (2 yr)	35,559	56,600,000	40	Herring 30-49 Sprat 36-48 Whiting 5-9	Greenwood (2008)
11	Pembroke	Daugleddau estuary, England	2000	1997 (2 mo)	3509	1,600,000*	38	Sand smelt 38 3-spined stickleback 14 Thick-lipped mullet 10 Nilsson's fish 9	Turnpenny et al. (1997)
12	Sizewell A	Suffolk coast, England	1200	1981-82 (1 yr)		3,700,000	73		Turnpenny et al. (1983)*
13	Coolkeeragh	Derry, northern Ireland	400	1989-90 (1 yr)		1,700,000	28		Moorehead & Service (1992)*
14	Oldbury-Upon Severn	Severn estuary, England	434	1971-76 (5 yr)		250,000	75		Claridge et al. (1986)*
15	Fawley	Southampton, England	2000	1973-74 (1 yr)		600,000	80		Holmes (1975)*
16	Hinkley Point B	Bristol Channel, England	1250	16 yr		990,000	73		Henderson (2009)
17	Kilroot	Belfast Lough, North Ireland	520	1989-90 (1 yr)		110,000	37		Moorehead & Service (1992)*
18	Gravelines	North Sea, Nord, France	5706	1981-82 (2 yr)		214,000,000	49		Blanpied-Wohrer (1984)*
19	Eems	Eems estuary, Netherlands	1700	1996-7 (1 yr)		18,000,000	34	Herring 28 Gobies 50 3-spined stickleback 7 Nilson's pipefish 4	Haddingh & Jager (2002)

20	Borssele	Netherlands	485	1994-5				Herring	80	<i>In</i> Hadderingh & Jager (2002)
								Sprat	12	
								Gobies	3	
21	ASIA 2nd Nuclear Power Plant	Kuosheng, Taiwan	1960	2000-4 (45 mo)	9,735		196	Rabbitfish	63	Liao et al. (2004)
				1987-90 (34 mo)	8,258		(4-31/mo) (5-48/mo)	Spiny pufferfish	20	
22	Karachi Nuclear Power Plant	Karachi, Pakistan	137	1974-77 (4 yr)			62	Terapon		Moazzam & Rizvi (1980)
								Grey mullet		
								Banded sergeant		
								Smooth blaasop		
								Sardinella		
23	Kapar Power Station	Kapar, Malaysia	2420	2004 (2 mo)	62,169	2,202,182	87	Glass perchlet	19 (3)#	This study
						(total biota = 8,500,000)	(total biota = 187 species)	Splendid ponyfish	12 (3)	
								Sagor catfish	8 (2)	
								Spotted scat (Greasyback prawn)	7 (2) (10)	
								(Banana prawn)	(5)	
								(Yellow prawn)	(4)	

number in parenthesis indicates % of total impinged biota

* in Henderson (2009)

Legend to Figures

Figure 1.

Location of Kapar Power Station (KPS), Selangor state, Malaysia.

Figure 2.

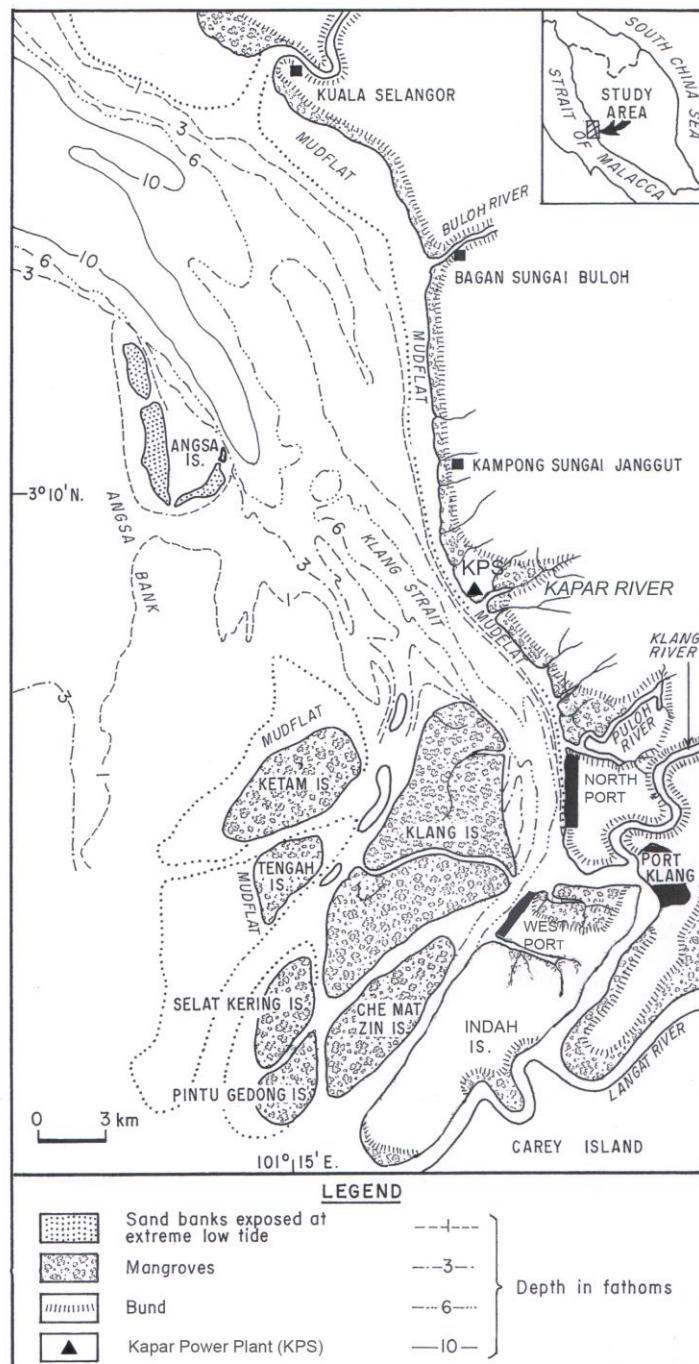
Curve of cumulative species number against sampling effort for Kapar Power Station screens. Dash line = fish; round dotted line = invertebrates; solid line = all biota; filled histogram = number of fish species; empty histogram = number of invertebrate species.

Figure 3.

Radar plots of abundance of impinged organisms (no./12hr) at Unit 1 (top 2 rows) and Unit 6 (bottom 2 rows) at Kapar Power Station, Malaysia, by faunal group, moon phase (q1, Q1= 1st quarter; fm, FM = full moon; q3, Q3 = 3rd quarter; nm, NM = new moon) and light condition (day time = small letters, night time = block letters). Vertical scale = abundance/12 hr.

Figure 4.

Average percentage weight of damaged marine organisms compared to those in good condition for five faunal groups impinged at Kapar Power Station, Malaysia.



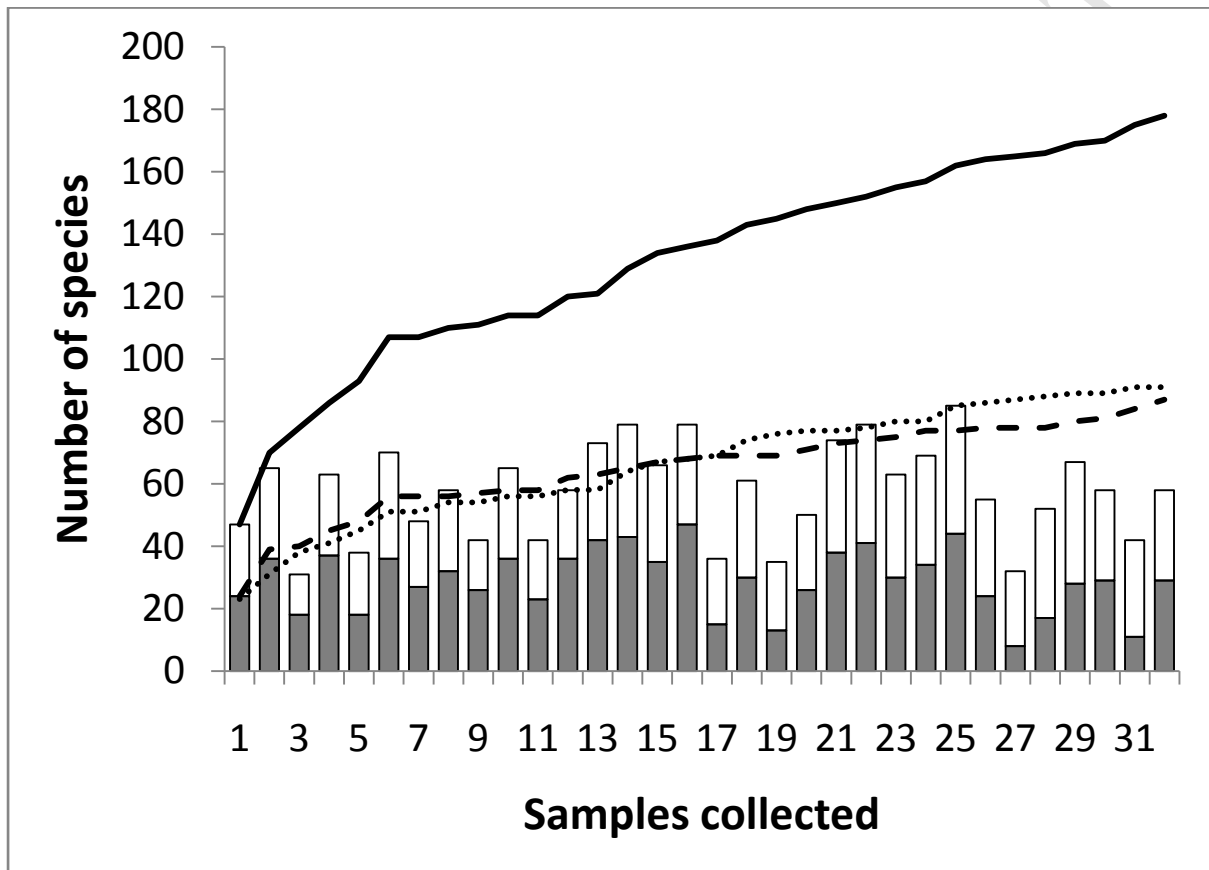
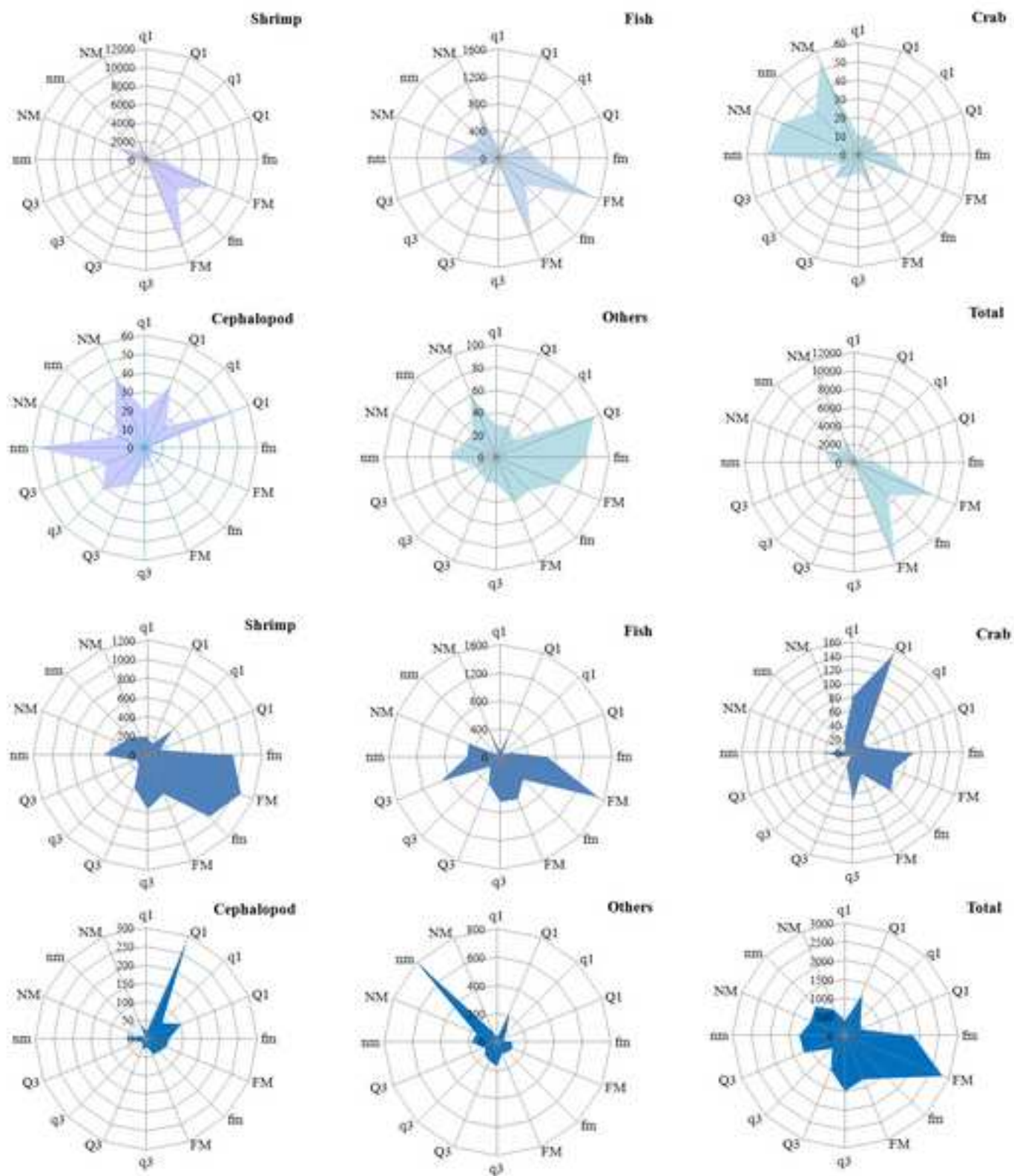


Fig 2



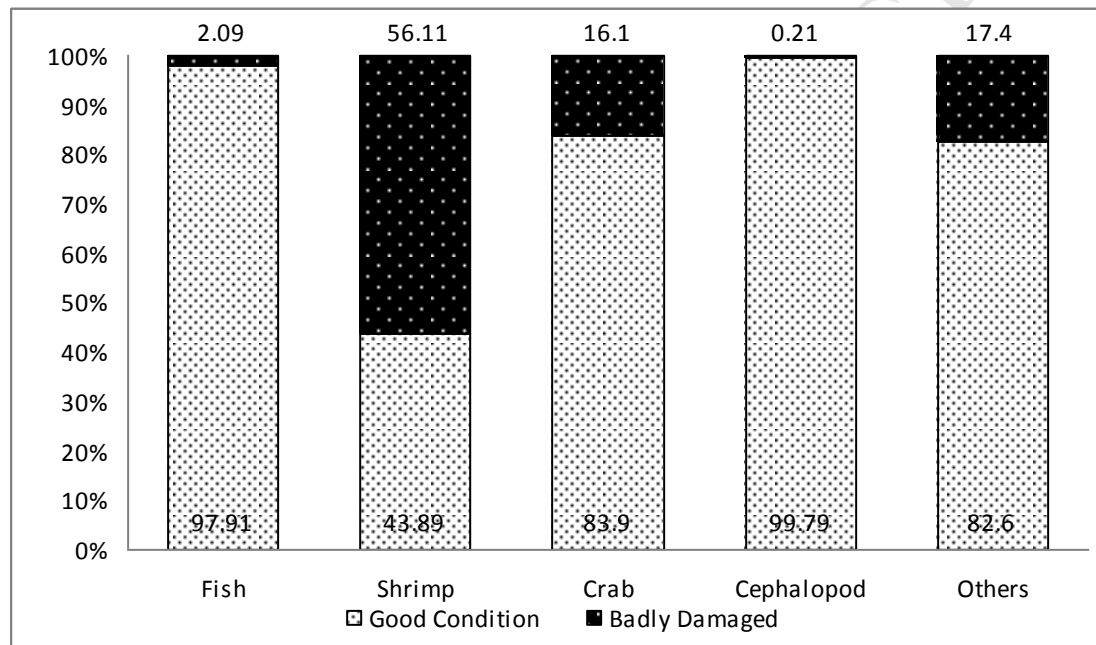


Fig.4

Appendix A.

List of impinged species sampled from cooling water intakes of Kapar Power Station, May 26 – July 19, 2004, ranked in order of total abundance.

	Species	Family/ Higher Taxa	Common Name	Abundance	Biomass g	Frequency %
1	** <i>Metapenaeus affinis</i>	Penaeidae	Greasy back shrimp	6186	10498	97
2	<i>Ambassis gymnocephalus</i>	Ambassidae	Glass perchlet	3083	7636	78
3	** <i>Penaeus merguensis</i>	Penaeidae	Banana prawn	2993	10411	88
4	** <i>Metapenaeus brevicornis</i>	Penaeidae	Yellow prawn	2372	4261	97
5	* <i>Thryssa kammalensis</i>	Engraulidae	Kammal thryssa	1899	4840	100
6	** <i>Leiognathus splendens</i>	Leiognathidae	Splendid ponyfish	1795	4507	91
7	* <i>Arius sagor</i>	Ariidae	Sagor catfish	1219	38410	88
8	* <i>Scatophagus argus</i>	Scatophagidae	Spotted scat	1047	15107	88
9	<i>Salmacis dussumieri</i>	Temopleuridae	Sea urchin	951	4416	94
10	** <i>Gerres erythrorurus</i>	Gerreidae	Deep-bodied mojarra	823	3195	88
11	** <i>Sepiella inermis</i>	Sepiidae	Spineless cuttlefish	791	14199	94
12	** <i>Lobonema smithii</i>	Rhizostomeae	White jellyfish	734	26176	19
13	** <i>Parapenaeopsis sculptilis</i>	Penaeidae	Rainbow prawn	650	1631	88
14	** <i>Dendrophysa russelii</i>	Sciaenidae	Goatee croaker	542	2933	75
15	** <i>Acetes</i> sp.	Sergestidae	Sergestid shrimp	510	150	75
16	** <i>Palaemon styliferus</i>	Palaemonidae	Caridean shrimp	403	550	66
17	* <i>Arius maculatus</i>	Ariidae	Spotted catfish	393	2195	75
18	** <i>Loligo</i> sp.	Loliginidae	Pencil squid	391	923	75
19	<i>Thais tissoti</i>	Muricidae	Tissot's rockshell	376	614	91
20	** <i>Parapenaeopsis maxillipedo</i>	Penaeidae	Torpedo shrimp	361	385	69
21	** <i>Metapenaeus ensis</i>	Penaeidae	Pink prawn	360	782	78
22	* <i>Charybdis japonica</i>	Portunidae	Japanese swimming crab	342	742	91
23	** <i>Parapenaeopsis coromandelica</i>	Penaeidae	Coromandel shrimp	318	463	59
24	** <i>Parapenaeopsis gracillima</i>	Penaeidae	Thin shrimp	302	332	66
25	** <i>Liza subviridis</i>	Mugilidae	Greenback mullet	294	5546	75
26	** <i>Pampus argenteus</i>	Stromateidae	Silver pomfret	283	830	59
27	** <i>Lepturacanthus savala</i>	Trichiuridae	Savalani hairtail	276	1360	84
28	<i>Neodorippe callida</i>	Dorippidae	Leaf porter crab	251	186	88
29	** <i>Pomadasys kaakan</i>	Haemulidae	Javelin grunter	248	1510	44
30	* <i>Herklotsichthys punctatus</i>	Clupeidae	Spotback herring	210	228	41
31	* <i>Anodontostoma chacunda</i>	Clupeidae	Chacunda gizzard shad	201	459	63
32	** <i>Cynoglossus lingua</i>	Cynoglossidae	Long tongue sole	191	1334	66
33	** <i>Johnius borneensis</i>	Sciaenidae	Sharptooth hammer croaker	188	1415	75
34	<i>Tetraodon fluviatilis</i>	Tetraodontidae	Estuarine blowfish	182	4109	72
35	* <i>Macrobrachium equidens</i>	Palaemonidae	Rough river prawn	171	701	72
36	<i>Carcinoscorpius rotundicauda</i>	Xiphosura	Horseshoe crab	162	13180	72
37	** <i>Drepane longimana</i>	Drepaneidae	Banded sicklefish	150	641	72
38	<i>Oxuderces dentatus</i>	Gobiidae	Goby	147	681	47
39	Sea cucumber sp. E	Holothuroidea	Sea cucumber	141	453	50
40	** <i>Johnius belangerii</i>	Sciaenidae	Belanger's croaker	139	1526	47
41	** <i>Perna viridis</i>	Mytilidae	Asian brown mussel	129	736	88
42	** <i>Siganus vermiculatus</i>	Siganidae	Vermiculated spinefoot	127	143	53
43	* <i>Myomenippe hardwickii</i>	Eriphiidae	Mangrove stone crab	119	1473	44

44	*	<i>Natica marculosa</i>	Naticidae	Sand snails	118	249	50
45	**	<i>Secutor insidiator</i>	Leiognathidae	Pugnose ponyfish	117	190	59
46		Ophiuroid sp.	Ophiuroidea	Brittle-stars	117	38	6
47		<i>Matuta planipes</i>	Calappinae	Flower moon crab	115	195	53
48	**	<i>Johnius carouna</i>	Sciaenidae	Caroun croaker	97	1772	69
49	**	<i>Octopus</i> sp.	Octopodidae	Benthic octopus	88	3667	69
50		<i>Butis koilomatodon</i>	Eleotridae	Saw-toothed gudgeon	86	335	56
51	**	<i>Metapenaeus lysianassa</i>	Penaeidae	Small white prawn	82	36	6
52	**	<i>Alepes djeddaba</i>	Carangidae	Djeddaba crevalle	81	116	44
53	**	<i>Plotosus canius</i>	Plotosidae	Gray eel-catfish	77	4993	59
54		<i>Doclea ovis</i>	Majidae	Spider crab	70	161	53
55	**	<i>Terapon theraps</i>	Terapontidae	Largescaled terapon	69	126	47
56		<i>Odontamblyopus</i> sp.	Gobiidae	Goby	69	1497	56
57		Sea cucumber sp. B	Holothuroidea	Sea cucumber	69	408	44
58		<i>Aniptumnus quadridentatus</i>	Pilumnidae	Crab	65	56	50
59		<i>Ctenotrypauchen microcephalus</i>	Gobiidae	Blind goby	62	465	59
60	**	<i>Harpadon nehereus</i>	Synodontidae	Bombay-duck	58	257	16
61	**	<i>Terapon jarbua</i>	Terapontidae	Jarbua terapon	57	305	41
62		<i>Boleophthalmus boddarti</i>	Gobiidae	Boddart's goggle-eyed goby	56	518	47
63		Sea cucumber sp. F	Holothuroidea	Sea cucumber	55	239	38
64	**	<i>Parapenaeopsis tenella</i>	Penaeidae	Smooth shell shrimp	54	26	6
65	**	<i>Oratosquilla interrupta</i>	Squillidae	Mantis shrimp	50	348	38
66	**	<i>Parapenaeopsis hungerfordi</i>	Penaeidae	Banded sharp-rostrum prawn	49	91	38
67	*	<i>Alpheus</i> sp.	Alpheidae	Pistol prawn	44	57	34
68	**	<i>Scomberoides commersonianus</i>	Carangidae	Talang queenfish	44	131	38
69	*	<i>Coilia dussumieri</i>	Engraulidae	Goldspotted grenadier anchovy	43	231	47
70		<i>Tachypleus gigas</i>	Xiphosura	Horseshoe crab	43	15555	47
71	*	<i>Mimocaris</i> sp.	Hippolytidae	Companion shrimp	37	46	13
72	*	<i>Ilisha melastoma</i>	Pristigasteridae	Indian ilisha	36	124	28
73		Sea cucumber sp. K	Holothuroidea	Sea cucumber	33	57	31
74	**	<i>Solen</i> sp.	Slecurtidae	Razor shell	31	48	22
75	**	<i>Lutjanus johnii</i>	Lutjanidae	John's snapper	31	198	34
76	*	<i>Allenbatrachus grunniens</i>	Batrachoididae	Grunting toadfish	30	677	19
77		<i>Clorida</i> sp.	Squillidae	Mantis shrimp	28	140	22
78	**	<i>Portunus pelagicus</i>	Portunidae	Flower crab	27	289	41
79	**	<i>Himantura bleekeri</i>	Dasyatidae	Whip-tail stingray	27	530	41
80		Jellyfish sp. 3	Scyphozoa	Jellyfishes	26	236	16
81	*	<i>Thryssa hamiltonii</i>	Engraulidae	Hamilton's anchovy/ thryssa	23	83	19
82		<i>Nereis</i> sp.	Neridae	Polychaete worms	22	17	16
83	*	<i>Cloridopsis scorpio</i>	Squillidae	Spotted squillid mantis prawn	22	70	22
84	**	<i>Eleutheronema tetradactylum</i>	Polynemidae	Fourfinger threadfin	21	143	19
85		Isopod species	Isopoda	Isopod	21	4	28
86		<i>Takifugu oblongus</i>	Tetraodontidae	Oblong blowfish	20	86	28
87	*	<i>Charybdis anisodon</i>	Portunidae	Two-spine arm swimming crab	20	503	19
88	**	<i>Miyakea nepa</i>	Squillidae	Smalleyed mantis shrimp	20	105	13
89	**	<i>Dasyatis zugei</i>	Dasyatidae	Pale edge stingray	19	611	34
90	**	<i>Cynoglossus puncticeps</i>	Cynoglossidae	Speckled tonguesole	19	101	28
91		Sea cucumber sp. L	Holothuroidea	Sea cucumber	19	48	28
92	*	<i>Glossogobius giuris</i>	Gobiidae	Bar-eyed goby	19	97	28
93	**	<i>Sillago sihama</i>	Sillaginidae	Silver sillago	18	163	25
94		Jellyfish sp. 5	Scyphozoa	Jellyfish	16	317	9
95		Jellyfish sp. 4	Scyphozoa	Jellyfish	16	152	6
96		<i>Eucrate</i> sp.	Geneplacidae	Goneplacid crab	16	26	13
97		<i>Crepidula</i> sp.	Calyptraeidae	Slipper limpet	15	4	6

98	*	<i>Triacanthus biaculeatus</i>	Triacanthidae	Shortnosed tripodfish	15	6	25
99	**	<i>Charybdis feriatius</i>	Portunidae	Crucifix crab	15	110	19
100		<i>Hyastenus diacanthus</i>	Majidae	Spider crab	14	20	13
101	**	<i>Harpiosquilla harpax</i>	Harpiosquillidae	Robber mantis shrimp	14	46	41
102		<i>Lagocephalus lunaris</i>	Lagocephalidae	Green rough-backed blowfish	14	48	28
103	*	<i>Setipinna taty</i>	Engraulidae	Hair-fin anchovy	13	92	9
104	**	<i>Nibea soldado</i>	Sciaenidae	Soldier croaker	13	56	25
105		<i>Bursa</i> sp.	Bursidae	Frog shell	12	29	13
106		<i>Medaeops potens</i>	Xanthidae	Xanthid crab	12	54	16
107	**	<i>Dictyosquilla foveolata</i>	Squillidae	Mantis shrimp	12	90	9
108	*	<i>Liza melinoptera</i>	Mugilidae	Otomebora mullet	12	58	19
109		<i>Stegostoma fasciatum</i>	Stegostomatidae	Zebra shark	11	37	25
110	*	<i>Zenarchopterus dispar</i>	Hemirhamphidae	Viviparous half-beak	11	15	16
111	**	<i>Oratosquilla perpensa</i>	Squillidae	Common squillid mantis shrimp	10	96	13
112		Sea cucumber sp. A	Holothuroidea	Sea cucumber	10	25	16
113		<i>Eurythoe</i> sp.	Polychaetes	Worm	10	50	9
114	*	<i>Charybdis</i> sp.	Portunidae	Swimming crab	10	11	16
115	**	<i>Otolithes ruber</i>	Sciaenidae	Tiger-toothed croaker	9	147	13
116		Sea cucumber sp. D	Holothuroidea	Sea cucumber	9	14	13
117		Jellyfish sp. 2	Scyphozoa	Jellyfishes	8	7819	3
118	**	<i>Alepes</i> sp.	Carangidae	Selar	8	7	3
119		<i>Scartelaos histophorus</i>	Gobiidae	Walking goby	8	45	16
120		Sea cucumber sp. G	Holothuroidea	Sea cucumber	7	6	9
121	*	<i>Arius venosus</i>	Ariidae	Veined catfish	6	58	6
122	**	<i>Scylla paramamosain</i>	Portunidae	Green mud crab	6	470	13
123		<i>Doclea rissoni</i>	Majidae	Spider crab	6	137	6
124	*	Caridean sp. 2	Palaemonidae	Caridean prawn	6	1	6
125	**	<i>Penaeus monodon</i>	Penaeidae	Giant tiger prawn	6	43	9
126		<i>Clibanaria infraspinatus</i>	Paguridae	Hermit crab	5	53	9
127		<i>Kurtus indicus</i>	Kurtidae	Indian hump head	5	11	9
128		Sea cucumber sp. H	Holothuroidea	Sea cucumber	5	12	9
129	*	<i>Osteogeneiosus militaris</i>	Ariidae	Soldier cat-fish	5	72	9
130		<i>Dorippoides facchino</i>	Dorippidae	Leaf porter crab	5	17	9
131	**	<i>Taeniura lymna</i>	Dasyatidae	Blue-spotted ribbon-tail ray	5	399	9
132	**	<i>Parapenaeopsis hardwickii</i>	Penaeidae	Sharp-rostrum prawn	5	8	9
133		<i>Calyptraea extintorium</i>	Calyptraeidae	Slipper limpets	4	2	3
134		Sea cucumber sp. I	Holothuroidea	Sea cucumber	4	7	6
135		Sea cucumber sp. M	Holothuroidea	Sea cucumber	4	18	6
136	**	<i>Johnius amblycephalus</i>	Sciaenidae	Bearded croaker	4	8	6
137		<i>Benthopanope</i> sp.	Pilumnidae	Hairy crab	4	21	6
138	*	Caridean sp. 1	Palaemonidae	Caridean prawn	4	3	6
139		Sea cucumber sp. N	Holothuroidea	Sea cucumber	4	78	6
140	**	<i>Sideria thyrsoidea</i>	Muraenidae	Slender moray	4	494	6
141	*	<i>Hyporhamphus gaimardi</i>	Hemirhamphidae	Gaimard's half-beak	4	10	6
142		<i>Vespicula trachinoides</i>	Tetrarogidae	Goblin fish	4	8	3
143	*	<i>Thais carinifera</i>	Muricidae	Rockshell	3	10	6
144	**	<i>Ilisha kampeni</i>	Pristigasteridae	Kampen's ilisha	3	3	6
145	**	<i>Sphyaena jello</i>	Sphyaenidae	Pickhandle barracuda	3	17	6
146	**	<i>Dasyatis kuhlii</i>	Dasyatidae	Blue-spotted stingray	3	290	6
147	**	<i>Synaptura commersonii</i>	Soleidae	Commerson's sole	3	112	6
148		Sea cucumber sp. C	Holothuroidea	Sea cucumber	2	7	6
149	*	<i>Arius caelatus</i>	Ariidae	Engraved catfish	2	109	3
150	*	Caridean sp. 3	Palaemonidae	Caridean prawn	2	1	3
151	**	<i>Alepes melanoptera</i>	Carangidae	Blackfin crevalle	2	3	6

152	**	<i>Lutjanus</i> sp.	Lutjanidae	Snapper	2	645	3
153	**	<i>Penaeus indicus</i>	Penaeidae	Indian white prawn	2	16	3
154	**	<i>Upeneus sulphureus</i>	Mullidae	Yellow goatfish	2	4	3
155	**	<i>Pecten</i> sp.	Pectinidae	Scallop	2	1	3
156		<i>Gobiopsis macrostoma</i>	Gobiidae	Longjaw goby	2	19	3
157	**	<i>Lutjanus argentimaculatus</i>	Lutjanidae	Mangrove red snapper	2	6	3
158	**	<i>Valamugil</i> sp.	Mugilidae	Mullet	2	3	3
159		<i>Ophichthys rhytidodermatoides</i>	Ophichthyidae	Wrinkled-skin snake eel	2	260	3
160	**	<i>Pseudorhombus arsius</i>	Paralichthyidae	Large-tooth flounder	2	34	3
161	**	<i>Elops machnata</i>	Elopidae	Tenpounder	2	17	3
162		<i>Prionobutis</i> sp.	Eleotridae	Gudgeon	2	4	3
163	*	<i>Strongylura strongylura</i>	Belonidae	Round-tail alligator gar	2	1	3
164	**	<i>Johnium carutta</i>	Sciaenidae	Karut croaker	2	47	3
165	*	<i>Anabas testudineus</i>	Anabantidae	Climbing perch	2	108	3
166	**	<i>Plotosus lineatus</i>	Plotosidae	Striped eel catfish	2	83	3
167		<i>Thalassina</i> sp.	Thalassinidae	Mud shrimp	2	2	3
168		Polychaete sp. D	Polychaeta	Polychaete worms	1	3	3
169		Polychaete sp. B	Polychaeta	Polychaete worms	1	1	3
170		Sea cucumber sp. J	Holothuroidea	Sea cucumber	1	3	3
171		Polychaete sp. A	Polychaeta	Polychaete worms	1	0	3
172	**	<i>Himantura uarnak</i>	Dasyatidae	Banded whiptail stingray	1	46	3
173		<i>Atherinomorus duodecimalis</i>	Atherinidae	Tropical silverside	1	1	3
174		<i>Diogenes diogenes</i>	Paguridae	Hermit-crabs	1	0	3
175		Polychaete sp. C	Polychaeta	Polychaete worms	1	2	3
176	**	<i>Platycephalus indicus</i>	Platycephalidae	Indian flathead	1	1	3
177	**	<i>Panna microdon</i>	Sciaenidae	Panna croaker	1	39	3
178	**	<i>Himantura marginatus</i>	Dasyatidae	Black-edged stingray	1	33	3
		Scianidae juveniles	Sciaenidae	Croaker juveniles	1172	2356	31
		Serranidae juveniles	Serranidae	Grouper juveniles	99	82	18
		Stomatopod post larval stage	Stomatopoda	Mantis shrimps	215	30	8
		Unidentified shrimps #			25231	40165	97
		Unidentified crabs #				1102	91
		Unidentified jellyfish #				18964	88
		Unidentified fish #				2574	91
TOTAL:					62169	306821	

** commercially-exploited

* low commercial value but consumed

unidentified due to highly damaged condition