Thermoshock Fish Mortality Investigation

Chris T. Walsh, Michael. P. Rodgers, Nick J. Thorne and
Wayne A. Robinson

NSW Department of Primary Industries
Batemans Bay Fisheries Centre
PO Box 17, Batemans Bay, NSW 2536

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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NON-TECHNICAL SUMMARY

Thermoshock Fish Mortality Investigation

PRINCIPAL INVESTIGATOR: Dr Chris Walsh

ADDRESS: NSW Department of Primary Industries
Batemans Bay Fisheries Centre
PO Box 17, Batemans Bay, NSW, 2536
Telephone: 02 4478 9111 Fax: 02 44727542

EXECUTIVE SUMMARY:

In 2011 TRUenergy P/L was required under their environmental permit to carry out a Thermoshock Fish Mortality Investigation at the Tallawarra Power Station, situated on Lake Illawarra. Consequently, NSW Department of Primary Industries (DPI) was engaged to assess the fish and invertebrate communities which are entrapped during thermoshock, to better understand the associated extent of their mortality under a range of conditions. Specifically, the diversity, abundance and mortality of fish and invertebrates was investigated during normal operational mode and during thermoshock for one year over a range of times and conditions.

NSW DPI completed two rounds of community sampling (summer and winter) at Tallawarra Power Station in 2011/12. A total estimate of 30 706 fish and 11 398 invertebrates, represented by 45 and 15 species respectively, were monitored in the fish return channel during thermoshock on 20 (5 days/5 nights/2 seasons) occasions. The community structure and high variability in abundance of fish and invertebrates entrapped during normal operational mode and during thermoshock was found to be similar to that historically reported in Lake Illawarra. Similarity in fish and invertebrate species assemblages between the two processes were found to be at their greatest at night during the summer period. Dependent upon season, fish communities were dominated by a few small to medium bodied taxa, with diversity and abundance highest during thermoshock than in normal operational mode. Invertebrate populations for both operations were also dominated by a few species (including jelly fish and prawns), however, their abundances were significantly greater during normal operational mode.

Based on visual observation, examination of the capture data and time of the year, it was evident that thermoshock greatly increased mortality in both fish and invertebrate species (up to 33% and 21% respectively). Dependent upon species, mortality rates were highly variable, with some species suffering minimal mortalities, while for others there were no survivors. Higher fish mortality predominantly occurred when water temperatures reached between 10 to 20°C above ambient conditions when abundances of animals were relatively higher during thermoshock. Moreover, there were significant differences in species size structure between populations of 'alive' and 'dead' individuals, with the larger fish of most species being more susceptible to the heating process. The results of this report are discussed and recommendations made to assist in mitigating the current thermoshock process and practices at Tallawarra Power Station, to provide a healthier fish community.

1. BACKGROUND

Power stations often require large quantities of water for the efficient operation of the plant (e.g., cooling water systems). This requirement of cooling water and the exhaustive demands on freshwater, has led power plants to locate in coastal sites where water is constantly available and at a relatively inexpensive cost. However, with the use of seawater comes the inherent problem of bio fouling in water delivery pipes. The usual way to avoid micro and macro fouling within a cooling system, especially inside the main condenser, is to apply chemical dosing of free chlorine and sulphuric acid. However, in recent years due to environmental concerns, there has been a shift towards power stations adopting a ‘thermoshock’ process to control biological growth inside the cooling water system and its equipment.

Tallawarra Power Station, situated along the shores of Lake Illawarra (10km south of Wollongong), is a 435 MW combined cycle natural gas power station responsible for producing electricity for the state during periods of high demand. The power station’s thermoshock process operates at night for one hour on an approximate fortnightly basis (depending on the rate of bio-fouling). In this closed cycle, the water heats up to a temperature of approximately 45ºC and eliminates all bio-fouling. Excess heated water is discharged through a separate and enclosed discharge pipe which rejoins the outlet canal prior to re-entering the lake. Currently, as part of Tallawarra Power Station’s environmental permits requirements, a range of fish protection measures has been implemented. These measures include: 1) the provision of a bar screen (120mm) which prevents large fish swimming into the inlet canal; and 2) a multiple disc screen (5mm) which filters out all fish, prawns, jellyfish etc. and transports them via a fish return channel (Fig. 1) back through an outlet canal which is connected to the lake.

During normal plant operation processes at Tallawarra Power Station, fish have been observed in the fish return channel in healthy condition. However, during the ‘thermoshock’ process, when fish and invertebrate populations are subject to elevated water temperatures, there have been reports of ‘fish kills’, both in the fish return channel and subsequently in the outlet canal. This is not unusual as water temperatures exceeding the normal threshold requirements of fish and invertebrates can have lethal and sub-lethal consequences (Verones *et al.* 2010). As a result of the observed fish mortality events, Tallawarra Power Station’s environmental permit requires them to carry out a Thermoshock Fish Mortality Investigation to better understand the thermoshock process, and the associated extent of fish mortality under a range of conditions.

2. METHODS

2.1. Water quality monitoring

Fish and invertebrate injury and mortalities within the thermoshock process are likely to be coincident with changes in water quality. Therefore variables, including dissolved oxygen and water temperature were recorded during each sampling occasion. The monitoring of water quality was done by a data logger within the fish return channel (Fig. 1.). The logger recorded water temperature every minute, while dissolved oxygen levels and water temperature were monitored at the sampling capture site using a water quality ‘Horiba’ which manually logs changes in water quality.

Figure 1. Fish return channel after screening and thermoshock

2.2. Fish and invertebrate sampling

Sampling periods: December 2011 – March 2012 (Summer)
June 2012 –September 2012 (Winter)

For each seasonal sampling period, the species diversity and abundance of fish and invertebrates in the fish return channel were monitored on 10 occasions (approximately once every two weeks) either in the day (between 0900 and 1200) or at night (2100-2400). This number of replications (5) over two seasons and two diel periods was required to generate scientifically robust results. On each occasion, fish and invertebrates were monitored while the system was in normal mode (i.e., operating at ambient temperatures) for 1hr, followed by another approximate 1hr when the system was in thermoshock mode. Fish and invertebrate species were captured in the return channel by netting (Fig. 2). Captured animals were then designated into water bins based on temperature ranges recorded during and above normal operational mode (i.e., ambient, 0-5, 5-10, 10-15, 15-20, 20-25 and >25°C). To ensure the health of the fish and invertebrates, as well as manage the large volume of animals moving through the system, a sub sampling procedure was adopted. This involved netting for a period of one minute intervals, followed by non-capture intervals (i.e., either one, two or three minutes) for each temperature bin.

During normal operational mode and during thermoshock, captured fish and invertebrates were assessed based on their condition (i.e., whether they were dead or alive). Fish and invertebrates were then identified (to species level), measured (to the nearest mm) and assessed for any physical damage (including mortality). Unidentified specimens were retained for laboratory examination to later classify them to species level. For all alive and dead fish and invertebrate species, the lengths of up to 50 individuals were measured, with live animals being returned to the outlet canal. Each fish was measured from the tip of the snout to either the fork of the tail (fork length) or to the tip of the tail (total length) for species with rounded tails. In the case of invertebrates, the carapace or mantle length as well as the distance from the eye socket to the end of the carapace (shrimps and prawns) were measured. Obvious signs of disease, injury, spawning condition and sex were also noted.

Figure 2. Netting used to capture fish and invertebrates.

2.3. Data analysis

A Factorial Analysis of Variance (ANOVA) was used to test for significant differences in the mean abundance of fish and invertebrates between normal and thermoshock operations (temperature), summer and winter sampling (season), and day/night (diel) effects. All abundance data were observed to meet the assumptions of normality and homogeneity of variance. Analyses were done using the Statistica 6 (Statsoft) software package with a *P* value of 0.05 considered significant.

The species assemblages of fish and invertebrate populations captured at Tallawarra Power Station were analysed using a 3 factor hierarchical PERMANOVA (Anderson 2001). In this model, temperature, season and diel were all fixed factors. To moderate effects of occasional high abundances, the data were log (x+1) transformed and the Bray Curtis similarity between all effects was calculated. All permutation tests were performed using Monte Carlo probabilities based on type 3 sums of squares and 9999 permutations. The Bray-Curtis similarity matrix was used to generate a 2 dimensional ordination of the sites through time using the MDS routine to aid interpretation. The model was then used to perform follow up pair wise comparisons to examine mean similarities between normal operational mode and thermoshock for season and diel effects among fish and invertebrate assemblages.

Size distributions within fish species that were captured ‘alive’ and ‘dead’ from combined season and day/night sampling data were compared using Kolmogorov-Smirnov (K-S) Two Sample Tests.

These analyses provide an assessment of the effect of thermoshock on fish population size structure and were done for species with 50 individuals or more recorded both ‘alive’ and ‘dead’ during sampling. K-S tests were done using the Monte Carlo estimate provided by SAS with a *P* value of 0.05 considered significant.

3. RESULTS

3.1. Water quality monitoring

From the onset of the thermoshock during each sampling occasion (day or night), water temperatures in the outlet canal rose consistently from ambient levels (summer, 22-25°C; winter, 16-18°C) to > 37°C within 60 minutes (Fig. 3). At the completion of thermoshock water temperatures declined rapidly, reaching ambient levels almost two hours after the process was initiated. In reverse, the DO levels declined from ≈ 8mg/L to ≈ 5mg/L at the highest water temperatures before increasing back to ambient levels at the completion of the thermoshock process. There were only minimal differences in water quality variables recorded between day and night samples.

3.2. Species diversity and abundance

Twenty rounds of summer (5 days/5 nights) and winter (5 days/5 nights) sampling have been successfully carried out in the fish return channel during 1hr of normal mode of operation and during thermoshock. A total of 1 859 fish representing 32 species and 25 210 invertebrates representing 15 species were captured during the normal mode of operation (Appendices 1 and 2); while 11 221 fish representing 45 species and 5633 invertebrates representing 15 species were captured during thermoshock (Appendices 3 and 4). In general, the diversity of fish species captured during the thermoshock process was higher than for those captured during normal operational mode, with similar numbers of species captured between the seasons and diel (day/night) periods (Fig. 4). Species diversity for invertebrates was higher during thermoshock than normal operational mode during the day for both winter and summer sampling only, although numbers captured were more highly variable between seasons and diel periods than those for fish species (Fig. 5).

Estimates of fish and invertebrates passing through the fish return channel during normal operational mode over the twenty sampling events were 4 205 and 54 563, respectively, while estimates passing through the fish channel during thermoshock were 30 706 and 11 398, respectively. Mean estimated abundances of fish passing through the fish return channel at each sampling occasion during thermoshock ranged from ≈ 700 during the night in winter mean peak of ≈ 3 000 individuals during the day in summer (Fig. 6). No significant differences in mean abundances were detected between seasons ($P > 0.1$) and day or night (diel) ($P > 0.1$) sampling events (Appendix 5). Mean estimated abundance of fish during normal operational mode were significantly less than those estimated during thermoshock (ANOVA: temp, $P < 0.01$, Appendix 5a) with the highest recorded mean abundance (≈ 700 individuals) of fish being at night during the summer season.

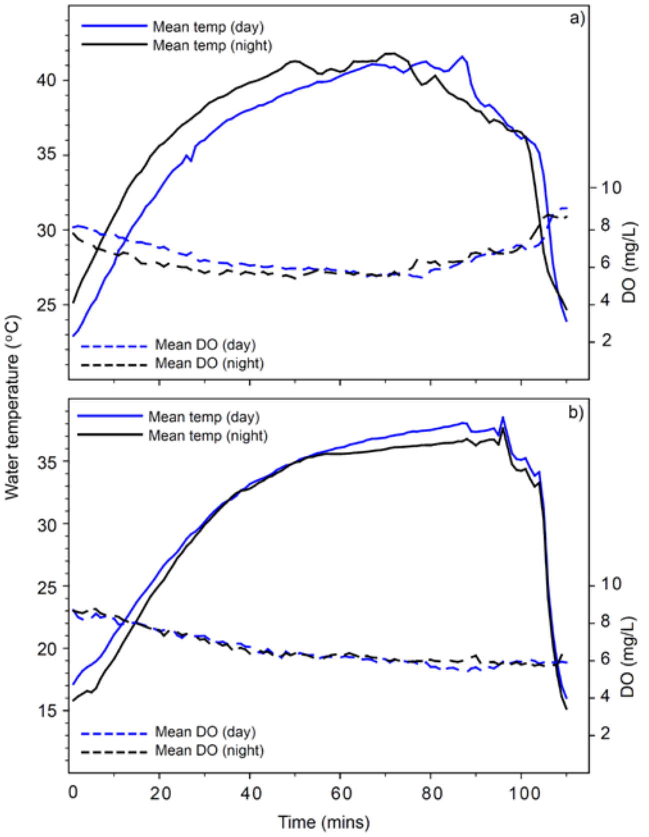

Figure 3. Mean water temperature (straight lines) and dissolved oxygen (DO) (dashed lines) recorded in the fish return channel during thermoshock for a) summer and b) winter sampling periods.

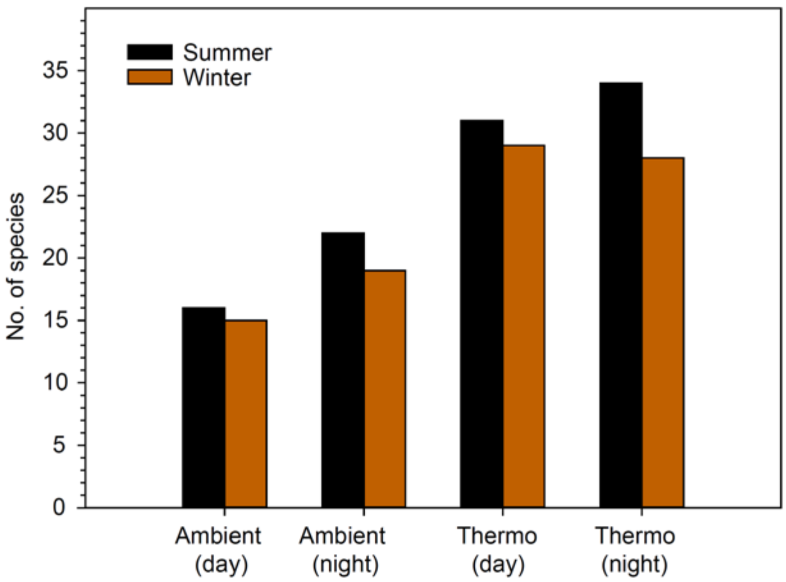

Figure 4. Number of fish species captured passing through the fish return channel during 1hr of normal operational mode (ambient) and during thermoshock.

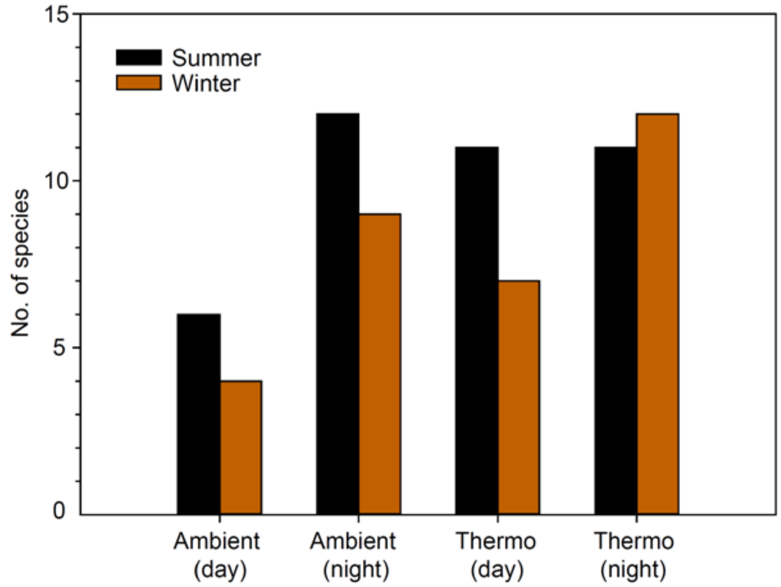

Figure 5. Number of invertebrate species captured passing through the fish return channel during 1hr of normal operational mode (ambient) and during thermoshock.

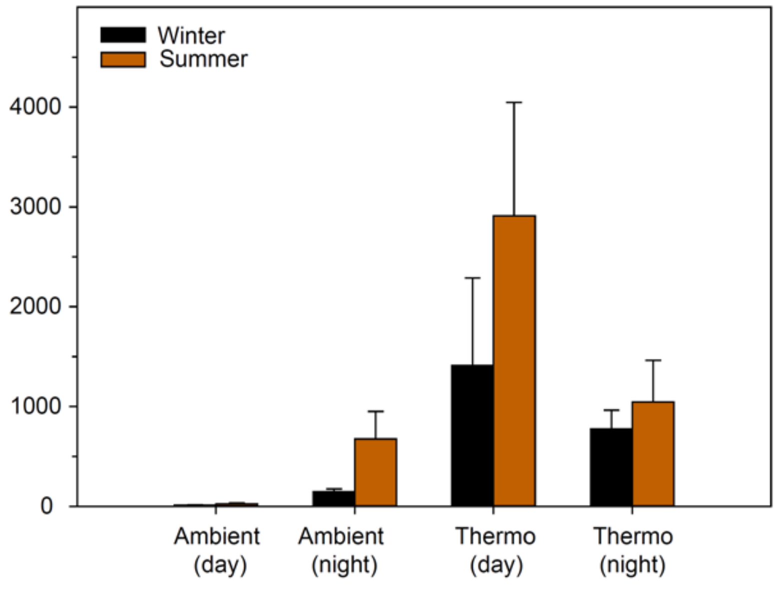

Figure 6. Mean (± s.e.) estimated abundances of fish passing through the fish return channel during 1 hr of normal operational mode (ambient) and during thermoshock.

In contrast, the mean number of estimated invertebrates passing through during normal operational mode and during thermoshock was higher at night (Fig. 7), however, there were no significant difference in mean invertebrate abundance between season ($P > 0.1$) and diel ($P > 0.1$) sampling events (Appendix 5). Significantly more invertebrates were estimated passing through at normal operational mode than through thermoshock (ANOVA: temp, $P < 0.0001$, Appendix 5b), with mean estimated abundance approaching ≈ 6000 individuals at night during the summer period (Fig. 7). There was no significant interaction between factors (season, temp and diel) when assessing fish ($P > 0.1$) and invertebrate ($P > 0.1$) assemblages using multivariate analyses (Appendix 6). Significant differences were found amongst all three factors tested, with pair wise comparisons between normal operational mode and thermoshock fish and invertebrate populations revealing the highest mean similarities were during the summer period at night (Figures 8 and 9).

Relatively higher numbers of fish were captured when temperatures increased between 10 and 15°C above ambient conditions during the summer period, and between 15 and 25°C during the winter period (Fig. 10). In contrast, relatively higher numbers of invertebrates were captured during the normal mode of operation for both seasonal periods, and continued to decrease throughout the rising temperatures associated with thermoshock (Fig. 11).

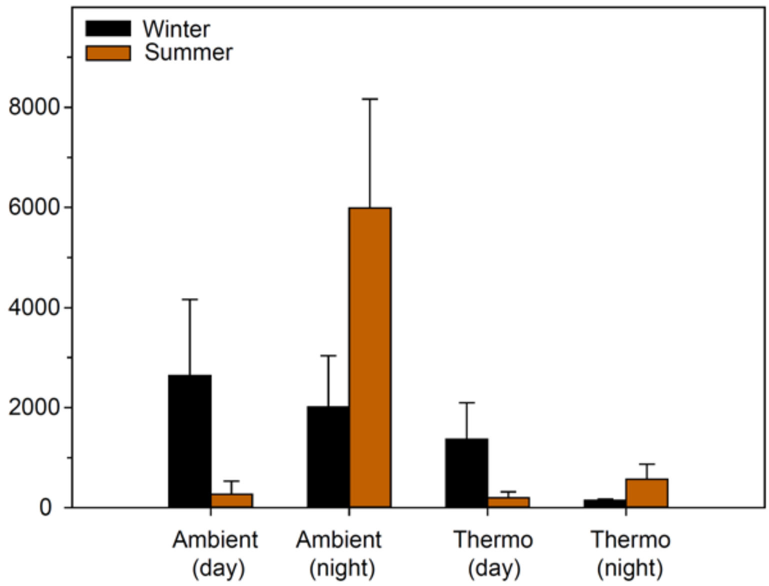

Figure 7. Mean (± s.e.) estimated abundances of invertebrates passing through the fish return channel during 1hr of normal operational mode (ambient) and during thermoshock.

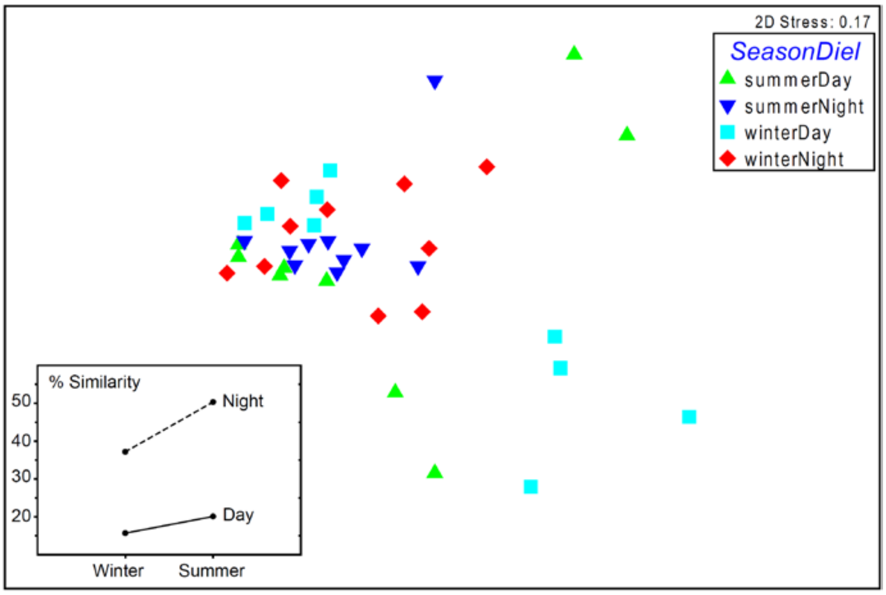

Figure 8. MDS plot of association of fish assemblages among seasons and diel periods. Mean percent similarity among groups between normal operational mode and thermoshock presented in insert.

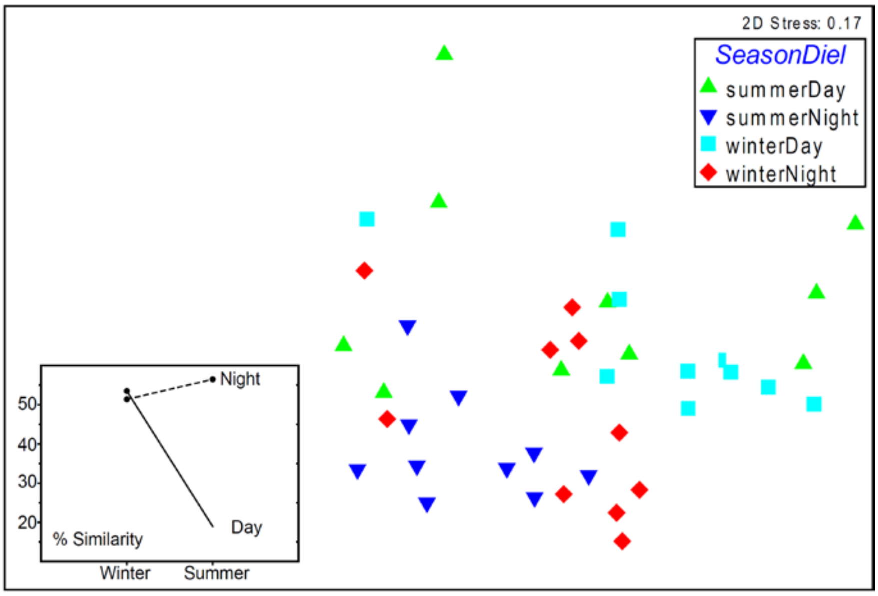

Figure 9. MDS plot of association of invertebrate assemblages among seasons and diel periods. Mean percent similarity among groups between normal operational mode and thermoshock presented in insert.

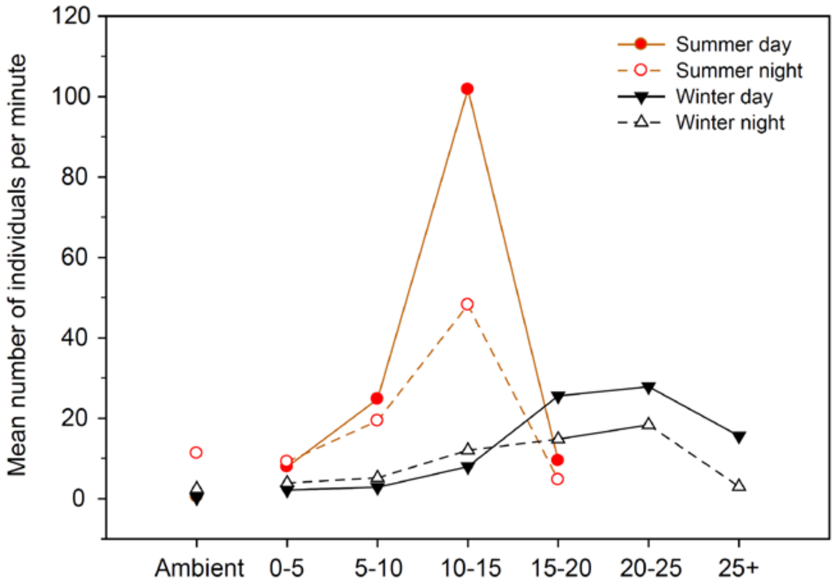

Figure 10. Mean number of fish per minute passing through the fish return channel during normal operational mode (ambient) and temperature ranges above ambient (thermoshock) over the summer and winter sampling periods.

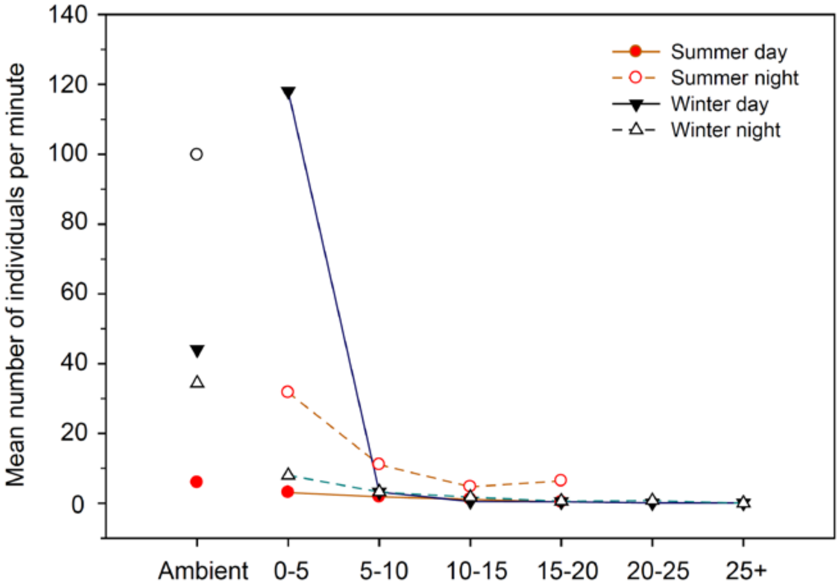

Figure 11. Mean number of invertebrates per minute passing through the fish return channel during normal operational mode (ambient) and temperature ranges above ambient (thermoshock) over the summer and winter sampling periods.

3.3. Fate of fish and invertebrates

In normal operational mode when sampling was during the day, there were minimal mortalities during both summer (3% of fish and 0% of invertebrates) and winter (11% of fish and <1% of invertebrates) (Appendix 1). In contrast, higher overall mortalities were recorded in the night sampling during summer (29% of fish and 45% of invertebrates) and winter (25% of fish and 13% of invertebrates) (Appendix 2). Coinciding with this increased mortality during the night sampling was a relative increase in the abundance and mortality rates of animals, including sandy sprat and Australian paste prawn.

During thermoshock when temperatures rose >10°C and >15°C above ambient conditions the majority of fish and invertebrates in the fish return channel were observed to have lost their equilibrium for both summer and winter sampling,. This was reflected in the overall increased mortality recorded for both fish and invertebrates captured in the fish return channel than for those captured during normal operational mode. In general, higher overall mortalities occurred during the winter sampling for fish (57%) and summer period for invertebrates (57%), while survival rates were similar between day and night for fish species (Table 1, Appendix 3 and 4). Mortality rates were highly variable between species and season, with some species suffering minimal mortalities, while for others there were no survivors. In particular, species caught in relatively high numbers that suffered high mortalities included the invertebrate Australian paste prawn and school prawn. The fish species – tarwhine, estuary glassfish, luderick and yellowfin bream also suffered high rates of mortality. In particular when water temperatures reached >10°C above ambient conditions, the survivability of these animals significantly decreased during both the summer and winter thermoshock (Figure 12).

Approximately 1% of the total fish captured alive and 3% of the total fish captured dead had experienced some form of injury associated with the thermoshock process (Appendix 6). This included significant wounds to the body (Fig 13a) as well as scale loss (Fig. 13b). On an individual level, for most species less than 4% of fish captured displayed some form of recent injury, while significant injury rates were only recorded for captured dead estuary glass fish (6%) and sandy sprat (15%) (Appendix 7).

Table 1. Percent mortality of overall abundance of fish and invertebrates monitored during normal operational mode and during thermoshock. The figures in bold represent 'actual' percentages, assuming that mortality in normal mode was due to handling.

	Normal mode		Thermoshock	
	Summer	Winter	Summer	Winter
Fish	28	24	39**(11)**	57**(33)**
Invertebrates	40	6	57**(17)**	27**(21)**

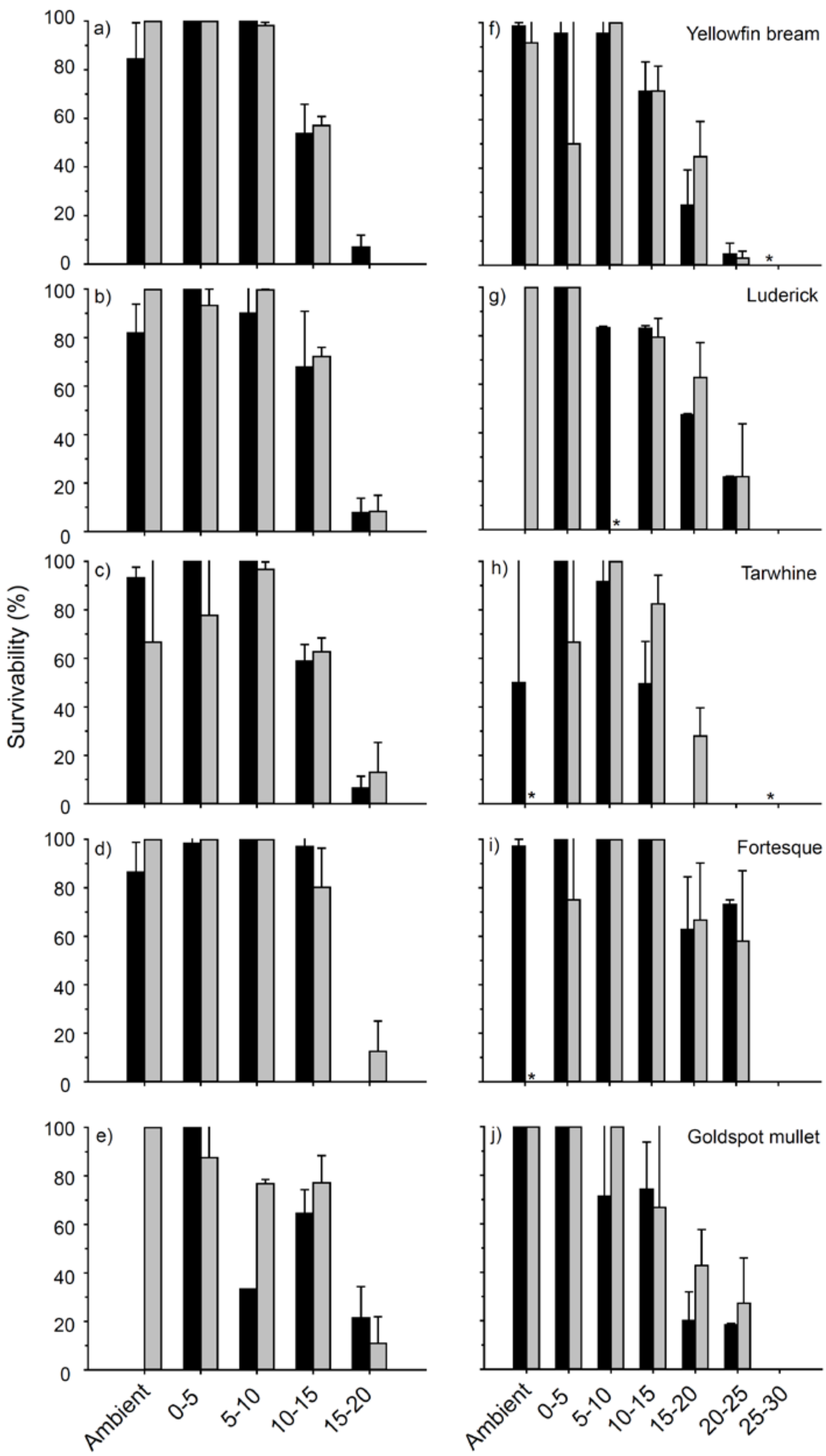

Figure 12. Mean survivability (s.e.) of five fish species captured in the fish return channel at ambient and temperature ranges above ambient (thermoshock) conditions during the day (grey bars) and night (black bars) for the summer (a-e) and winter (f-j) sampling periods.

3.4. Differences in size structure

In general, the majority of fish and invertebrates sampled during the study were either small-bodied species, or juveniles of medium-bodied species. Mature medium sized fish were also captured during particular times of the year. K-S tests revealed that 70% and 58% of species had significantly different size structures between alive and dead captured individuals for the summer and winter sampling period, respectively (Appendix 7). For all these fish, except for sandy sprat in the winter sampling period, thermoshock resulted in higher mortality on larger individuals within species (Fig.14, Appendix 8).

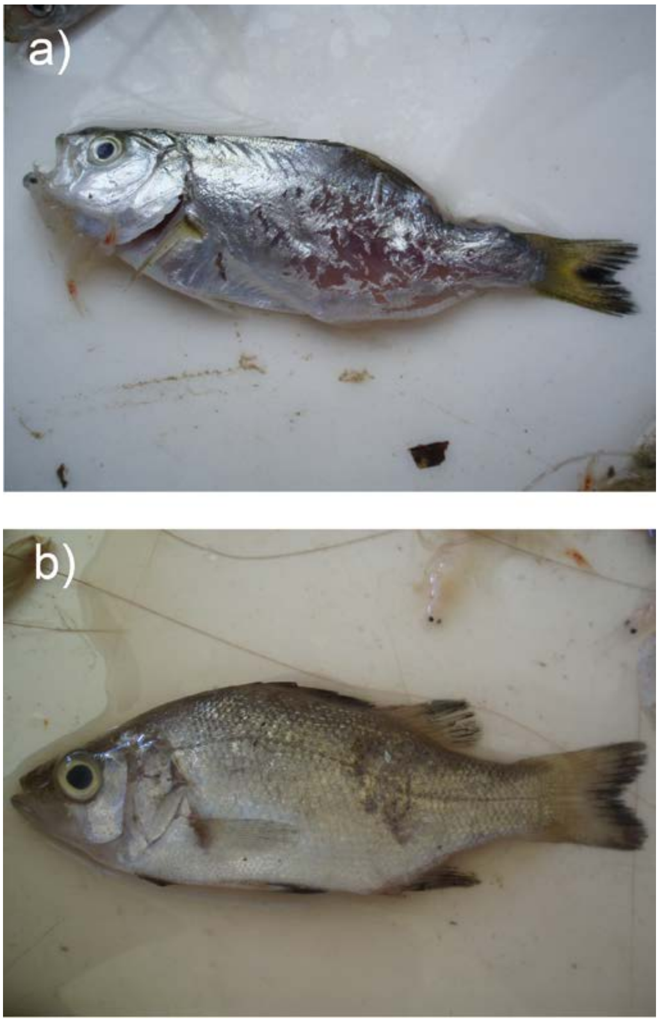

Figure 13. Photographs of juvenile a) tailor and b) estuary perch showing signs of injury sustained during the thermoshock process.

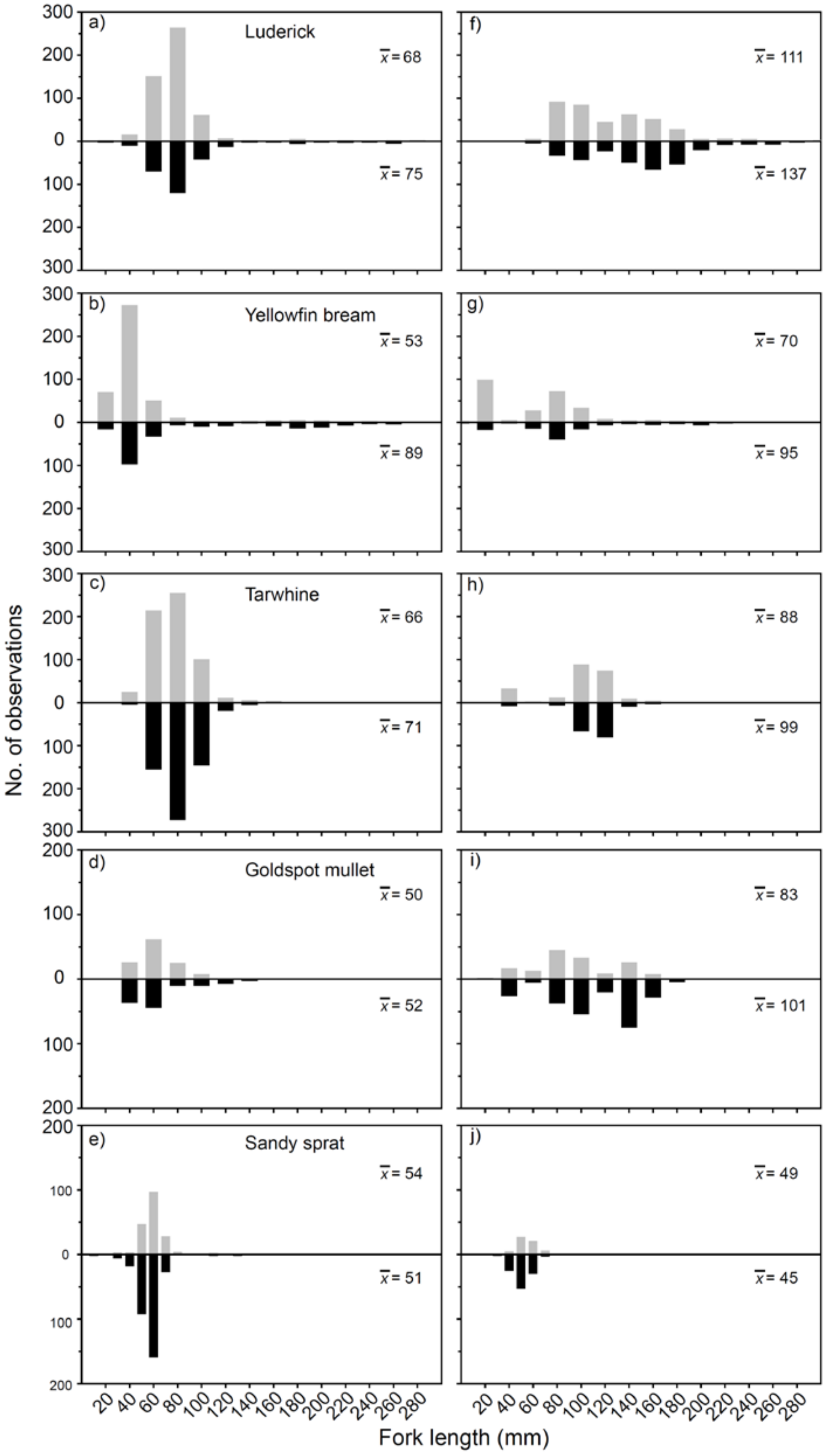

Figure 14. Comparison of size distributions and mean fork lengths (mm) of alive (grey bars) versus dead fish (black bars) sampled during (a–e) summer and winter (f-j) thermoshock for five fish species.

4. DISCUSSION

Overall, 45 fish species and 15 invertebrate species were captured using the fish return channel during thermoshock. A higher diversity of fish species (45 compared to 32) were captured during thermoshock than during normal operational mode over the summer and winter periods, while similar numbers of invertebrate species (15) were captured during both operations. This level of species richness within Tallawarra Power Station is similar to that examined in previous community studies done in the adjacent Lake Illawarra (Williams *et al.* 2004, Jones and West 2005). Although these authors each captured 56 fish species, their studies were done across all four seasons over a three year period, providing a greater chance of capturing more cryptic species within the lake. Similar to these earlier studies, the fish and invertebrate assemblages at Tallawarra comprised of many species that were rarely caught, and more often in low numbers, and a few common species that were captured in large numbers (Appendices 1-4). In particular, the dominant species caught during the normal operational mode where the smaller bodied fishes (e.g., sandy sprat, estuary glass fish), while during thermoshock the juveniles of the medium to large bodied species (e.g., tarwhine, luderick, yellowfin bream) made up the majority of the catch. For invertebrates, Australian paste prawns, school prawns and jelly fish were the dominant species captured during both the normal operational mode and thermoshock.

Apart from the large variation in the total number of species or numbers of fish and invertebrates caught between the normal operational mode and thermoshock, there were few consistent patterns observed in species richness and/or abundance between day and night and among seasons. In particular, species assemblages between both processes for fish and invertebrates were most similar during the summer period at night. Jones and West (2005) found species composition in Lake Illawarra was different between years, but seasonal samples within each year were similar to each other. Although there was no significant seasonal or diel effect on overall abundance of fish and invertebrates captured at Tallawarra Power station, the high variability in numbers indicated that small scale biophysical characteristics including rainfall, wind direction, tidal and moon phase, may have played a major role in influencing communities, at least on an individual species level (Jones and West 2005; Azilia and Chong 2010). For example, the influx of new recruits into Lake Illawarra such as tarwhine and luderick during the summer months, meant that relatively higher numbers of these species were captured during the same period in the fish return channel. Moreover, higher abundances of prawns (penaeids) and shrimps were captured consistently during the nightime than throughout the day. Azilz and Chong (2010) found that penaeids were subject to higher impingement rates in power stations during the night time. Such species become active at night when in the day they burrow under sediment to avoid predators.

For fish, relative abundance increased with rising water temperatures peaking at 10-15°C and 15-25°C above ambient conditions for both summer and winter, respectively. Possible reasons for the increase in fish diversity and abundance during high water temperatures may be the attraction of fish to warmer water in combination with the lethal and sub-lethal effects of heat stress preventing fish from avoiding the area. For invertebrates, higher relative abundances were caught during normal operational mode or ambient conditions. Being passive swimmers, invertebrates were more likely to be entrapped in the normal operational mode due to higher water velocities than those consistent with the thermoshock process. There were considerable mortalities among fish and invertebrates sampled in the fish return channel during normal operational mode. In particular, high mortality rates (57%) recorded for invertebrates during the summer period was likely an artefact of the higher abundance of animals moving through the system, in combination with their handling through the DPI sampling process. Small-bodied invertebrates, such as paste prawns are highly vulnerable to the stress associated with ‘screening’, as well as from their capture by netting in the fish return channel. Adding to these stresses is the vulnerability of fish and invertebrates to the presence of jellyfish. Visual observations made during sampling confirm that mortality is associated with the presence of jellyfish, and that this effect is further exacerbated when captured animals are confined with jellyfish in the capture nets. Previous species composition studies by

Virgona and Henry (1987) and Scanes *et al.* (1990) have also found that high mortalities are associated with fish and invertebrates coming into contact with jellyfish nematocysts.

During thermoshock, along with increase in species diversity and abundance, there was a significant reduction in survival rates among the fish and invertebrates sampled. Overall, 39% and 57% of fish and 57% and 27% of invertebrates did not survive the thermoshock process during the summer and winter periods, respectively. When thermoshock water temperatures reached >10°C and >15°C above ambient conditions for both summer and winter sampling, respectively, higher mortalities of both fish and invertebrates were witnessed and recorded, with some fish and invertebrates more susceptible to the heating process than others. This observation, and data was confirmed by the fact that only a small proportion of the captured ‘dead’ and ‘alive ’population displayed injuries related to turbulence and screening. There was no attempt to quantify the effect of our sampling technique on the end survival of fish and invertebrate species, as this was not possible within the scope of the study. However, as indicated above, the stress associated with handling would likely have increased the mortality rates of fish and invertebrate species. Therefore, if the overall percentages of mortality associated with the normal operational mode can be attributed to netting and handling alone, then the difference in mortality rates between this mode and thermoshock may be considered ‘actual, mortality. This would account for up to 33% for fishes and 21% in invertebrates in the winter period (Table 1). Even with this coarse estimation, there is no doubt that high water temperatures had a significant influence upon their direct and indirect survival.

Apart from the overall low survival associated with thermoshock, there were significant differences in the size structure of ‘alive’ and ‘dead’ individuals within species. In particular, higher survivability was recorded predominantly among the smaller individuals of most species, with the larger captured fish of most species being more susceptible to the heating process. Interestingly, among the medium-bodied fish species there was little evidence of mature fish (adults) being observed or captured, indicating that they are either avoiding the heated water, or they were not within the vicinity of the area. Although there is the provision of a bar screen (120mm) which is designed to prevent large fish swimming into the inlet canal, this screening would not preclude even the largest adults of those species captured in the fish return channel. Previous studies have shown that large and rapid changes in water temperature can potentially impact all aquatic biota both directly and indirectly, particularly those with less well developed thermo-regulatory capacities (Beitenger *et. al* 2000). Moreover, the susceptibility of a fish to temperature shock, including its behaviour, has also been found to be dependent upon the age of the fish, time of the year, as well as habitat composition (Ryan and Preece 2003). Although there was no attempt in this study to quantify the effect on the long term survivability of animals subjected to thermoshock, it is possible that any change in behaviour as a result of the process, including loss of equilibrium, may render them more susceptible to other predators on their return to the outlet canal (Beitenger *et. al* 2000).

5. CONCLUSIONS AND RECOMMENDATIONS

Although only one summer and one winter period were examined at Tallawarra Power Station, the high degree of replication of sampling events within this study has allowed the determination of the diversity, abundance and fate of fish and invertebrates entrapped during thermoshock. Apart from the general lack of adult medium to large-bodied fishes, the community structure and high variability in abundance of fish and invertebrate populations entrapped during the thermoshock process was found to be similar to that found in the neighbouring Lake Illawarra. Higher species richness and abundance were recorded for fishes during thermoshock, while similar numbers of invertebrate species and higher numbers of individuals were caught during normal operational mode. Mortality rates increased for fish and invertebrates when subjected to thermoshock, with some animals being more susceptible to the heating process than others. Moreover, the size structure of ‘dead’ vs ‘alive individuals within the majority of fish species examined revealed larger fish were more susceptible to the heating process.

In conclusion, the thermoshock process at Tallawarra Power Station does contribute to a significant increase (up to a third of all individuals) in mortality rates for entrapped fish and invertebrates. However, it must be noted that the thermoshock process on average is only carried out for an hour once a week. Therefore, the abundances examined during thermoshock within this study represent only a very small proportion of the total number of individuals moving through Tallawarra Power, and indeed those occupying the adjacent lake. Nevertheless, recommendations to assist in improving the health of the fish communities during thermoshock at Tallawarra Power Station would include:

1) Providing some form of distraction or mitigation to keep fish and invertebrates away from the inlet chamber. At present during thermoshock, fish and invertebrates within this vicinity are subjected to high turbulence and extreme water temperatures. Any attempt to prevent animals from entering the area, or assist in leaving the area, would improve their survival. Possible deterrents to reduce entrainment of fish and invertebrates from entering the inlet chamber would include the construction of rolling drum screens; sonic deterrents; and/or bubble curtains. However, the retrofitting of these deterrents to existing infrastructure at Tallawarra Power Station would be logistically difficult and expensive. A cost effective alternative would be to alter the thermoshock process to allow animals more time to move to favourable areas. For example, allowing the heating element of the thermoshock process to be delayed (i.e., provide turbulence without heat for a specified time) or even slowed down may allow individuals to retreat before they are subjected to elevated heat stress.

2) In combination with the above, the introduction of ambient temperature water immediately prior to the animals entering the fish return channel. This would allow heat stressed individuals to acclimate more quickly to their desired water temperatures. In any case, such mitigation procedures would require follow up monitoring to ensure their success in reducing abundances and improving the health of the fish and invertebrate entrapped during thermoshock.

3) The investigation into the possible removal of jellyfish from the inlet canal prior to their entering the screening process, as well as ensuring that the final outlet of the fish return channel is immersed underwater. The latter would assist the large quantities of animals affected by thermoshock (immobilised) to be protected from avian predators.

6. REFERENCES

Azila, A. and Chong, V. C. 2010. Multispecies impingement in a tropical power plant, Straits of Malacca. *Marine Environmental Research* **70**, 13-25

Beitinger, T. L., Bennett, W. A. and, McCauley, R. W. (2000). Temperature tolerances of North American freshwater fishes exposed to dynamic changes in temperature. *Environmental Biology of Fishes* **58**, 237-275.

Jones, M. V. and West, R. J. (2005). Spatial and temporal variability of seagrass fishes in intermittently closed and open coastal lakes in south-eastern Australia. *Estuarine, Coastal and Shelf Science* **64**, 277-288.

Ryan, T. J. and Preece, R. M. (2003). Potential for thermal shock in the Murray-Darling Basin. A report to the Murray-Darling Basin Commission (Natural Resources Management Strategy). Victorian Department of Sustainability and Environment, Heidelberg, and NSW Department of Sustainable Natural Resources, Parramatta.

Scanes, P. R., Jacobs, N. E. and Williams, R. J. (1990). The impact of Tallawarra Power Station on the fish and fisheries of Lake Illawarra. Prepared for the Electricity Commission of NSW. Fisheries Research Institute, November 1990.

Verones, F., Hanafiah, M. M, Pfister, S.,Huijbregts, M. A .J., Pelletier, G. J. and Koehler, A. (2010). Characterisation factors for thermal Pollution in freshwater aquatic environments. *Environmental Science and Technology* **44**, 9364-9369.

Virgona, J. L. and Henry, G. W. (1987). Investigation into the commercial and recreational fisheries of Lake Macquarie and Lake Tuggerah. Department of Agriculture and Fisheries. Fisheries Research Institute. Internal Report No. 28, December 1987.

Williams, R. J., Louden, B. and Jones, M. (2004) Fish Biodiversity in Lake Illawarra: A review of three recent surveys. *Wetlands* **21**, 168- 182.

7. APPENDICES

Appendix 1. Summary table of species caught and estimated abundances, including percent mortality of a) fish and b) invertebrates monitored during 1hr of normal operational mode over the summer sampling period.

a)	Length range	Day sampling (*n* =5)			Night sampling (*n* =5)		
Common name	(mm)	Actual	Estimate	% mortality	Actual	Estimate	% mortality
Sandy sprat	21 - 104	2	3	50	925	2163	36
Estuary glassfish	7 - 67	4	6	0	199	408	14
Yellowfin bream	27 - 72	9	9	0	103	287	11
Tarwhine	40 - 84	2	5	0	50	137	10
Tailor	27 - 158	4	10	50	44	96	36
Eastern fortescue	36 - 70	1	1	0	36	76	17
Luderick	42 - 82	12	23	0	24	52	12
Port Jackson glassfish	34 - 56				17	52	6
Threebar porcupinefish	54 - 285	2	3	0	8	20	0
Fourline striped grunter	44 -107				7	16	14
River garfish	32 - 150	14	19	0	7	17	57
Australian anchovy	17 - 64				6	14	50
Common silverbiddy	32 - 116	19	19	0	4	10	0
Sea mullet	60 - 126				3	6	33
Short-finned eel	421 - 740				3	6	0
Largemouth goby	36 - 39				2	4	50
Common stinkfish	37 -37				1	2	0
Estuary perch	104-104				1	2	0
Goldspot mullet	47 - 64	2	2	0	1	2	100
Sand whiting	89 - 89				1	2	0
Silver trevally	29-29				1	2	0
Smooth toadfish	85 - 85				1	3	0
Black sole	165 - 229	3	6	0			
Diamondfish	92 - 92	1	2	0			
Glassgoby	17 - 21	8	16	0			
Six-spined leatherjacket	47 - 82	5	5	0			
Slender longtom	314 - 314	1	1	0			
Total		**89**	**130**	**3**	**1444**	**3378**	**29**

b)	Length range	Day sampling (*n* =5)			Night sampling (*n* =5)		
Common name	(mm)	Actual	Estimate	% mortality	Actual	Estimate	% mortality
Australian paste prawn	2 - 12	249	266	0	10791	21645	46
School prawn	5 - 23	6	8	0	1697	3756	68
Jellyfish	#	1016	1071	0	1637	4361	0
Dumpling squid	8 - 96				37	94	22
Eastern king prawn	16 - 64				12	34	27
Mud crab	11 - 16	1	1	0	8	16	0
Long-armed shrimp	3 - 10				7	15	57
Sydney octopus	420 - 520				7	14	0
Broad squid	40 - 50				2	4	100
Blue swimmer crab	82 - 168	2	2	0	1	2	0
Brown tiger prawn	9 - 9				1	2	0
Hairy backed crab	49 - 54				1	2	0
Bottle squid	30 - 30	1	1	0			
Total		**1275**	**1349**	**0**	**14201**	**29944**	**42**

No measurements were taken

Appendix 2. Summary table of species caught and estimated abundances, including percent mortality of a) fish and b) invertebrates monitored during 1hr of normal operational mode over the winter sampling period.

a)	Length range	Day sampling (*n* =5)			Night sampling (*n* =5)		
Common name	(mm)	Actual	Estimate	% mortality	Actual	Estimate	% mortality
Sandy sprat	32 - 63				114	247	54
Estuary glassfish	28 - 62	4	8	0	29	80	10
Yellowfin bream	18 - 81	7	14	14	27	84	4
Tarwhine	24 - 106				4	11	25
Tailor	24 - 180	2	4	50	13	31	23
Eastern fortescue	30 - 58				38	91	3
Luderick	64 - 124	3	6	0			
Port Jackson glassfish	31 - 54	1	2	0	18	43	11
Threebar porcupinefish	50 - 160	7	14	0	19	58	0
Fourline striped grunter	116 - 116				1	4	0
River garfish	109 - 147	1	2	0	4	12	0
Australian anchovy	43-43				1	2	0
Common silverbiddy	32 - 126	1	2	0	1	2	0
Sea mullet	113 - 285	2	4	50	2	4	0
Largemouth goby	31 - 31				1	3	0
Goldspot mullet	33 - 133	1	2		6	20	0
Smooth toadfish	75 - 75				1	4	0
Glassgoby	25 - 25	1	2	100	1	3	0
Southern blue-eye	27 - 27	1	2	0			
Tamar goby	7 - 64	1	2	0	10	26	0
Silver sweep	36-36				1	2	0
Rough leatherjacket	31 - 31	1	2	0			
Southern pygmy leatherjacket	58 - 58	2	4	0			
Total		**35**	**70**	**11**	**291**	**727**	**25**

b)	Length range	Day sampling (*n* =5)			Night sampling (*n* =5)		
Common name	(mm)	Actual	Estimate	% mortality	Actual	Estimate	% mortality
Australian paste prawn	4 - 11	61	122	46	1565	5885	24
School prawn	6 - 19	3	6	0	551	1464	4
Jellyfish	#	6540	13080	0	962	2597	0
Dumpling squid	14 - 100				21	48	0
Eastern king prawn	17 - 17				2	6	0
Long-armed shrimp	3 - 8	1	2	0	26	54	19
Blue swimmer crab	13 - 25				2	6	0
Southern calamari	340 - 340				2	6	0
Pistol shrimp	45 - 45				1	3	0
Total		**6605**	**13210**	**<1%**	**3129**	**10060**	**13**

No measurements were taken

Appendix 3. Summary table of species caught and estimated abundances, including percent mortality of a) fish and b) invertebrates monitored during thermoshock over the summer sampling period.

a)	Length range	Day sampling (*n* =5)			Night sampling (*n* =5)		
Common name	(mm)	Actual	Estimate	% mortality	Actual	Estimate	% mortality
Luderick	10 - 267	1673	5152	22	282	568	19
Tarwhine	32 - 148	1524	4744	32	797	1737	46
Glassgoby	12 - 26	535	1070	99	8	16	50
Yellowfin bream	27 - 274	396	1010	34	156	352	49
Eastern fortescue	5 - 70	213	461	9	266	545	16
Goldspot mullet	27 - 134	175	478	47	42	92	48
Estuary glassfish	15 - 87	115	319	48	214	432	49
Common silverbiddy	28 - 155	88	292	50	126	257	74
Tailor	16 - 239	87	239	71	67	135	78
Fourline striped grunter	20 - 114	49	151	45	215	453	62
Diamondfish	36 - 128	42	117	19	22	44	23
Sea mullet	44 - 332	36	125	61	6	12	83
Empire gudgeon	24 - 120	29	101	62	2	4	100
Estuary perch	86 - 116	20	61	0	24	48	13
River garfish	31 - 150	19	44	58	10	22	70
Silver trevally	29 - 76	14	38	71	3	7	33
Sandy sprat	7 - 121	10	22	80	145	326	86
Stripey	43 - 128	9	29	44	21	42	38
Threebar porcupinefish	31 - 175	9	23	11	6	12	0
Black sole	47 - 213	5	10	20	1	2	0
Bullrout	174 - 277	5	15	0	3	6	0
Six-spined leatherjacket	61 - 190	5	14	40	1	2	0
Largemouth goby	15 - 87	4	12	75	6	13	67
Sand whiting	48 - 140	3	8	67	5	10	60
Stout longtom	33 - 33	2	4	100			
Happy moments	114 - 114	1	3	0			
Smooth toadfish	63 - 63	1	2	0			
Snapper	72 - 105	1	3	100	3	7	67
Southern herring	54 - 150	1	2	0	2	5	0
Yellow-eyed leatherjacket	214 - 214	1	4	100			
Yellowtail scad	25 - 292	1	4	0	3	6	100
Australian anchovy	52 - 52				1	2	100
Green moray	84 - 84				1	3	100
Long-finned eel	360-360				1	2	0
Port Jackson glassfish	33 - 65				12	24	50
Sand mullet	37 - 164				18	36	33
Slender longtom	115 - 115				1	3	0
Striped catfish	82 - 82				1	2	0
Total		**5073**	**14555**	**37**	**2471**	**5228**	**45**

b) Common name	Length range (mm)	Day sampling (*n* =5) Actual	Estimate	% mortality	Night sampling (*n* =5) Actual	Estimate	% mortality
Jellyfish	#	285	570	0	6	12	0
Australian paste prawn	10 - 12	82	157	46	1018	2039	81
Greasyback prawn	8 - 25	38	92	0			
Long-armed shrimp	4 - 19	30	60	3	26	55	23
School prawn	5 - 23	27	59	26	335	674	59
Eastern king prawn	8 - 23	11	25	9	16	32	44
Blue swimmer crab	10 - 176	6	13	0	3	6	33
Mud crab	10 - 39	3	8	33	3	6	33
Brown tiger prawn	9 - 52	3	6	33			
Sydney octopus	82 - 820	1	2	100	6	12	33
Southern calamari	30 - 83	1	3	0			
Dumpling squid	11 - 15				4	9	50
Hairy backed crab	13 - 67				3	7	0
Blue-ringed octopus	107 - 178				1	2	100
Total		**487**	**995**	**10**	**1421**	**2854**	**74**

No measurements were taken

Appendix 4. Summary table of species caught and estimated abundances, including percent mortality of a) fish and b) invertebrates monitored during thermoshock over the winter sampling period.

a)	Length range	Day sampling (*n* =5)			Night sampling (*n* =5)		
Common name	(mm)	Actual	Estimate	% mortality	Actual	Estimate	% mortality
Luderick	46 - 282	386	1149	41	341	1095	49
Tarwhine	22 - 157	172	473	74	87	202	52
Glassgoby	17 - 28	81	162	99	11	22	91
Yellowfin bream	20 - 229	203	509	50	216	550	48
Eastern fortescue	21 - 63	151	391	10	115	345	23
Goldspot mullet	18 - 166	382	1354	73	117	475	73
Estuary glassfish	26 - 82	549	1794	62	66	197	48
Common silverbiddy	33 - 140	14	33	36	6	14	33
Tailor	25 - 128	32	69	63	16	38	75
Fourline striped grunter	38 - 136	34	104	74	6	21	100
Diamondfish	43 - 122	1	3	0	9	26	11
Sea mullet	19 - 372	100	290	91	88	288	93
Estuary perch	5 - 210	112	377	60	45	173	49
River garfish	46 - 172	11	28	27	12	28	25
Silver trevally	42 - 118	5	10	40	2	4	50
Sandy sprat	21 - 64	7	15	71	42	102	95
Threebar porcupinefish	12 - 229	10	20	30	9	18	0
Bullrout	158 - 240				3	6	0
Largemouth goby	29 - 41	1	2	0	3	7	67
Sand whiting	101 - 111	2	4	50	1	2	0
Smooth toadfish	75 - 134	1	3	0	3	6	0
Southern herring	153 - 153	1	2	0			
Yellowtail scad	26 - 37	3	6	67	1	2	0
Australian anchovy	51 - 70	1	2	100	1	2	100
Port Jackson glassfish	17 - 67	110	236	45	86	214	74
Southern blue-eye	26 - 26	2	4	50			
Yellowfin leatherjacket	66 - 242	3	6	0	4	10	0
Tamar goby	57 - 57				1	3	0
Silver sweep	24 - 24				1	2	0
Common toadfish	42 - 42	1	2	0			
Common jollytail	31 - 87	4	8	100	5	15	100
Widebody pipefish	83 - 83	1	2	100			
Total		**2380**	**7056**	**58**	**1297**	**3867**	**55**

b)	Length range	Day sampling (*n* =5)			Night sampling (*n* =5)		
Common name	(mm)	Actual	Estimate	% mortality	Actual	Estimate	% mortality
Jellyfish	#	3337	6674	0	51	103	0
Australian paste prawn	2 - 9	39	81	41	72	210	49
Long-armed shrimp	4 - 12	26	56	23	24	61	54
School prawn	6 - 21	8	16	50	150	301	5
Eastern king prawn	8 - 8				1	2	0
Blue swimmer crab	15 - 71	2	4	0	2	4	0
Sydney octopus	627 - 700	1	3	0	2	8	100
Southern calamari	60 - 266				3	6	33
Dumpling squid	16 - 28				2	6	100
Hairy backed crab	58 - 58				1	3	100
Blue-ringed octopus	40 - 80	2	6	100	1	2	100
Pistol shrimp	6 - 6				1	3	100
Total		**3415**	**6839**	**1**	**310**	**710**	**20**

No measurements were taken

Appendix 5. *F* ratios and test of significance for the fixed three factor analysis of variance on the effects of season, temperature and diel on abundances of a) fish and b) invertebrates passing through the fish return channel.

a) Fish					
Intercept	30646731	1	30646731	20.90288	0.000069
season	3347994	1	3347994	2.28353	0.140567
temp	17425828	1	17425828	11.88544	0.001605
diel	1853762	1	1853762	1.26438	0.269189
season x temp	945322	1	945322	0.64477	0.427914
season x diel	314410	1	314410	0.21445	0.646438
temp x diel	6741735	1	6741735	4.59826	0.039701
season x temp x diel	1904882	1	1904882	1.29924	0.262812
Error	46916758	32	1466149		
Total	110097422	39			
b) Invertebrates					
Intercept	109916728	1	109916728	19.97533	0.000092
season	540934	1	540934	0.0983	0.755908
temp	47330134	1	47330134	8.60138	0.006162
diel	10865639	1	10865639	1.97463	0.169592
season x temp	3629867	1	3629867	0.65966	0.422681
season x diel	38785861	1	38785861	7.04861	0.012258
temp x diel	21592108	1	21592108	3.92397	0.056252
season x temp x diel	13701684	1	13701684	2.49003	0.124405
Error	176083938	32	5502623		
Total	422446893	39			

Appendix 6. Multivariate PERMANOVA comparison on the effects of season, temperature and diel factors on assemblages of a) fish and b) invertebrates passing through the fish return channel.

a) Fish						
Source	*df*	*SS*	*MS*	Pseudo-*F*	*P* (perm)	perms
Season	1	5202.2	5202.2	3.4235	0.0011	9919
Diel	1	6793.1	6793.1	4.4704	0.0001	9919
Temp	1	17588	17588	11.575	0.0001	9920
Season x Diel	1	1163.7	1163.7	0.7658	0.6757	9929
Season x Temp	1	3374.7	3374.7	2.2208	0.0231	9917
Diel x Temp	1	4778.1	4778.1	3.1444	0.0021	9925
Season x Diel x Temp	1	1055.6	1055.6	0.6947	0.7404	9920
Residuals	32	48626	1519.6			
Total	39	88582				

b) Invertebrates						
Source	*df*	*SS*	*MS*	Pseudo-*F*	*P* (perm)	perms
Season	1	4203.8	4203.8	3.8908	0.006	9919
Diel	1	11475	11475	10.621	0.001	9919
Temp	1	14675	14675	13.583	0.001	9920
Season x Diel	1	1185	1185	1.0968	0.341	9929
Season x Temp	1	1249.7	1249.7	1.1567	0.342	9917
Diel x Temp	1	2408.4	2408.4	2.2291	0.058	9925
Season x Diel x Temp	1	454.93	454.93	0.42106	0.811	9920
Residuals	32	34574	1080.4			
Total	39	70227				

Appendix 7. Summary table of the overall percent of injured fish captured during thermoshock.

	Alive			Dead		
Common name	**No. caught**	**injury**	**%**	**No. caught**	**Injury**	**%**
Australian anchovy	5		0	5		0
Black sole	8		0	1		0
Bullrout	11		0			
Common jollytail	1		0	8		0
Common silverbiddy	115	1	1	144		0
Common stinkfish				1		0
Common toadfish	1		0			
Diamondfish	61		0	14		0
Eastern fortescue	544		0	101		0
Empire gudgeon	11		0	20		0
Estuary glassfish	510	1	0	352	20	6
Estuary perch	111	4	4	91	3	3
Fourline striped grunter	124		0	161		0
Glassgoby	18		0	196		0
Goldspot mullet	262	4	2	344	3	1
Green moray				1		0
Happy moments	1		0			
Largemouth goby	7		0	10		0
Long-finned eel	1		0			
Luderick	865	18	2	567	6	1
Port Jackson glassfish	121		0	122		0
River garfish	49		0	29		0
Rough leatherjacket	1		0			
Sand mullet	13		0	5		0
Sand whiting	5		0	7		0
Sandy sprat	232	7	3	408	63	15
Sea mullet	35	1	3	202	7	3
Short-finned eel	3		0			
Silver sweep	2		0			
Silver trevally	11		0	14		0
Six-spined leatherjacket	9		0	2		0
Slender longtom	2		0			
Smooth toadfish	7		0			
Snapper	1		0	3		0
Southern blue-eye	1		0	2		0
Southern herring	3		0	1		0
Southern pygmy leatherjacket	2		0			
Stout longtom				2		0
Striped catfish				1		0
Stripey	17		0	13		0
Tailor	98		0	167	1	1
Tamar goby	11		0	1		0
Tarwhine	692	3	0	759	6	1
Threebar porcupinefish	65		0	5		0
Widebody pipefish	1		0			
Yellow eyed leatherjacket	1		0			
Yellowfin bream	660	6	1	408	9	2
Yellowfin leatherjacket	7		0			
Yellowtail scad	3		0	5		0
Grand Total	**4708**	**45**	**1**	**4172**	**118**	**3**

Appendix 8. Summary table of the mean size of captured alive and dead individuals during thermoshock for the summer and winter sampling periods, as well as appropriate K-S tests.

	Summer						Winter					
	Alive		Dead		KS test		Alive		Dead		KS test	
species	*n*	mean	*n*	mean	*D*	*P*	*n*	mean	*n*	mean	*D*	*P*
Common silverbiddy	99	50	138	72	0.35	***						
Eastern fortescue	282	43	59	46	0.15	0.11						
Estuary glassfish	265	54	171	53	0.12	0.07						
Estuary perch							69	122	88	125	0.15	0.27
Fourline striped grunter	113	84	131	90	0.34	***						
Goldspot mullet	117	50	103	52	0.13	0.22	145	83	241	101	0.31	***
Luderick	498	68	265	75	0.12	*	367	111	302	137	0.28	***
Port Jackson glassfish							99	42	114	41	0.16	0.06
Sandy sprat	177	54	300	51	0.21	***	55	49	108	45	0.20	0.06
Tailor	130	62	202	78	0.38	***						
Tarwhine	602	66	593	71	0.13	***	90	88	166	99	0.48	***
Yellowfin bream	413	52	202	89	0.30	***	247	70	206	95	0.36	***

* <0.01, ** <0.001, ** <0.0001

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