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Thermal preferences of two cohorts of juvenile silver
kob, *Argyrosomus inodorus*
(Pisces: Sciaenidae)

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In partial fulfillment of the requirements for a Masters of Science degree in
Applied Marine Science

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Abstract

The silver kob, *Argyrosomus inodorus*, has been identified as a viable species for mariculture in South Africa due to its high demand and market value as well as the necessary biological traits such as high fecundity and fast growth rates. In order for the full scale commercial production to become a reality however, it is important that the environmental conditions required for optimum growth at each phase of the species development are fully understood. Until recently, this sciaenid species was misidentified along with the dusky kob, *Argyrosomus japonicus*, as *Argyrosomus hololepidotus*, a fact that resulted in a poor understanding of the life history characteristics of the species and therefore the implementation of a poor management plan. As a result, wild stocks have been heavily over-exploited with spawner biomass-per-recruit ratios estimated at 2.9-12.5% of the pristine level. This study hypothesized that juvenile silver kob would exhibit a preferred temperature when a choice was available to them, and that this preferred temperature might change with age. Two cohorts of juvenile silver kob were acclimatized at 18°C and then subjected to identical temperature preference trials using temperature gradient tanks where the temperature ranged between 16 and 21.5°C as well as to identical isothermal control trials where the temperature throughout the tanks was 18°C. Salinity was kept constant at 35ppt and photoperiod remained 12L:12D throughout. After a day of acclimation, observations were done over a five day period until the distribution of fish within the tanks had stabilized and that final temperature preferendum could be determined. During this time, dissolved oxygen concentrations were measured continuously to ensure that oxygen did not become limiting but remained above 6.4ppt. Results showed that the juveniles did indeed exhibit a preferred temperature with a range of 16.3 to 17.6°C for the first cohorts, and 16.9 to 18.1°C for the second. This difference between the preferred temperature ranges of the two age classes was found to be significant ($p < 0.01$) by a Mann Whitney U Test. Kolmogorov-Smirnov tests showed no significant difference ($p < 0.01$) between the tanks of the isothermal control trials indicating that there was no shoaling behaviour or individual tank bias affecting the results.

Introduction

Silver kob, *Argyrosomus inodorus* (Griffiths and Heemstra), is an important linefish in the South African linefishery (Griffiths, 1997) with a distribution running from northern Namibia on the west coast of southern Africa (17.18S, 11.39E) to the Kei River mouth on the east coast of South Africa (32.37S, 28.25E) (Griffiths and Heemstra, 1995) (Figure 1).

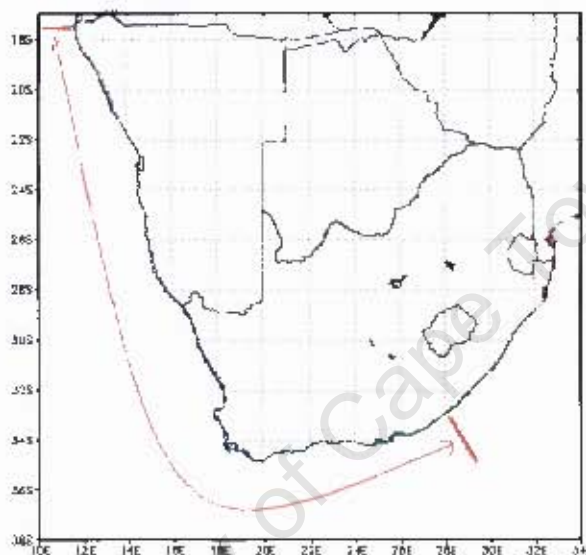


Figure 1: Distribution of silver kob, *Argyrosomus inodorus*, along the coast of Southern Africa.

Sea surface temperatures in this region range from 15°C on the west coast to 25°C in the east during summer and from 13°C to 22°C during winter (Figure 2). Until recently, this sciaenid species was misidentified as *Argyrosomus hololepidotus*, a species name which mistakenly also included the dusky kob, *Argyrosomus japonicus* (Griffiths, 1999). As a result, most of the early literature on the species is now considered incorrect and not much is known about the life history of *A. inodorus*. This has resulted in the poor management and over exploitation of silver kob in South African waters with wild stocks depleting rapidly and spawner biomass-per-recruit ratios estimated at 2.9-12.5% of the pristine level (Griffiths, 1997). Despite this, the large size and palatability of these fish ensure that the market value and demand remain high, making it one of the most valuable species caught by the fishery between Cape Point and East London (Griffiths, 1997).

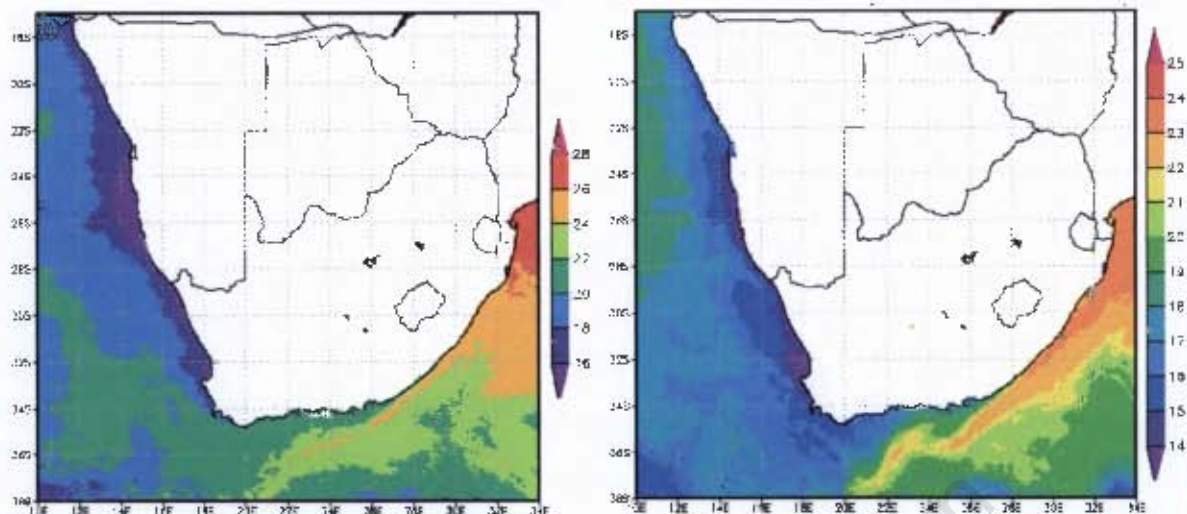


Figure 2: Time-averaged area plot showing sea surface temperatures (11 micron day) during summer (left) and winter (right) using remote sensing data gathered by MODIS and generated using Giovanni (NASA 2007).

Aquaculture in South Africa is a small but rapidly growing industry which, until recently, was primarily focused on the cultivation of abalone, mussels and oysters. With the growing success of integrated aquaculture in other parts of the world (Chopin *et al.*, 2005), many South African farms are looking towards expanding their pre-existing infrastructure to include the farming of either seaweeds or finfish. This is seen as a cost-effective and efficient way to increase market share and expand into new areas while decreasing the risk to the farm as its success will not solely be based on the demand for one particular species. Finfish species found in southern African waters which have been identified as candidate species for commercial production include carpenter (*Argyrozona argyrozona*), red roman (*Chrysoblephus laticeps*) and spotted grunter (*Pomadasys commersonii*) (Hoffman *et al.*, 2000).

Irvin and Johnston (I&J) have identified silver kob as a viable species for aquaculture and have successfully spawned and reared larvae from wild caught parent stocks. The species shows the correct traits needed for mariculture, including high fecundity, fast growth rates, reaching a size at 50% maturity of 310 mm in 1.3 years (Griffiths, 1999) and a high demand and market value (Bok, 2007 pers. comm.). However, in order to reach full scale commercial production, it is important that the optimal abiotic and biotic conditions for growth are determined (Deacon, 1997). These are factors such as temperature, salinity and stocking density which, at the correct level, promote efficiency and maximize growth.

Deacon (1997) stated the growth of fish is dependent on the relationship between food intake, metabolism and environmental factors which he classified into five distinct functional categories after Fry (1947), i.e., controlling, limiting, masking, directive and lethal factors. Environmental factors are designated into these categories according to their influence on metabolic processes (Deacon, 1997). Controlling factors such as temperature and pH govern the rates of reaction of metabolic processes, while limiting factors such as oxygen level restrict the supply or removal of metabolites and therefore limit growth. Masking factors such as salinity have a mitigating effect on other environmental factors through some regulatory device, while directive factors such as photoperiod signal the animal to respond to a particular characteristic of the environment. Finally lethal factors are factors which lead to the breakdown of metabolic processes and finally death and these include high temperature and salinity (Deacon, 1997). These factors are the key to determining the environmental conditions necessary for optimum growth and knowledge of them and their interactions can lead to the development of an aquaculture protocol for a particular species. Before these interactions can be understood, it is necessary to assess each variable independently (Fry, 1971; Deacon, 1997) and while this approach ignores the statistical interactions between factors, Fry (1971) determined that this apparent shortcoming may be lessened by ensuring that the experimental sequence is correct and that trials are performed under controlled conditions.

Few environmental factors have a larger influence on fish metabolism and hence growth than temperature (Jobling, 1997). It has consistently been identified as the primary abiotic factor controlling key physiological, biochemical and life history processes in fish (Beitinger and Fitzpatrick, 1979 as cited in Deacon, 1997). Under optimal environmental conditions, metabolic processes are optimized and consequently, all activities related to catabolism, including growth, are maximized (Deacon, 1997). As ectotherms, fish have virtually no capacity to regulate their body temperatures in fluctuating environmental conditions (Barros *et al.*, 2006) and must therefore rely on behavioural responses and mechanisms in order to thermoregulate satisfactorily. This includes behaviours such as habitat choice and distribution in the water column. The study of the relationship between temperature and growth has been widely researched for many species (Björnsson *et al.*, 2001; Kling *et al.*, 2006; Garcia-Esquivel *et al.*, 2007) and the responses of fish to temperature are most often described in terms of thermal limits, optimum temperature and preferred temperature (Deacon, 1997). The thermal limits are the lowest and highest temperatures at which a fish can survive, while the optimum temperature is the temperature at which maximum growth can be achieved. The preferred temperature or zone of final thermal preferendum, is defined as the narrow range of temperatures where fish will congregate, if given a choice (Reynolds and Casterlin, 1979). This preferred temperature range is species specific and independent of any previous thermal history such as acclimation temperature (Jobling, 1981). Several studies on other species of fish (Crawshaw, 1979; Jobling, 1981; Britz and Hecht, 1987) have shown a strong correlation between the preferred temperature of a species and the temperature required for its optimal growth. This correlation has led to the conclusion that temperature preference studies may be used as a rapid and cost-effective way to determine the optimal temperature for growth in an aquaculture environment.

Temperature preference can be classified into two groups, namely acute thermal preferendum and final temperature preferendum (Fry, 1947). Acute temperature preferendum is determined over a short time period and is therefore dependent on the acclimation temperature, while final temperature preferendum is determined only when the distribution of the fish has stabilized and is therefore not dependent on any previous

thermal history (Hecht, 1994). Fry (1947) defined the final temperature preferendum as a temperature around which all individuals (of a given species) will ultimately congregate, regardless of their thermal experience before being placed in the gradient. Determining the temperature preference of a species of fish using thermal gradient tanks may be seen as a rapid way to assess optimum temperature, however, a number of these past studies exhibited numerous experimental bias's including 'end of tank' bias and observer bias, where fish distribution is affected by an individual preference for a specific area in the tank or by any disturbances caused by the observer, respectively. These factors can be eliminated however, by performing an isothermal control trial (Birtwell *et al.*, 2003) and by covering the tanks as much as possible so that the observer goes unnoticed by the fish.

In order for the farming of silver kob to be as efficient and cost-effective as possible, it is important that these preferred and optimal temperature ranges be determined for each phase of the fish's development. For this reason, two different cohorts of *A. inodorus* juveniles were subjected to the same experimental procedures, the hypotheses being:

H₀₁ – There is no preferred temperature for juvenile *A. inodorus*

H_{A1} – Juvenile *A. inodorus* have a preferred temperature

H₀₂ – There is no difference in the preferred temperature of the two size classes of *A. inodorus*

H_{A2} – There is a difference in the preferred temperature of the two size classes of *A. inodorus*

As juvenile fish often change their distribution as they get older, these data will ensure that aquaculture conditions will be kept optimal at each stage of their life cycle.

Materials and Methods

Two different age classes, or cohorts, of juvenile silver kob were obtained from the I&J finfish hatchery in Danger Point, the first group was spawned in October 2005 and the second group in November 2006. The fish were transported to the Marine and Coastal Management (M&CM) Research Aquarium in Seapoint, Cape Town where experimental trials took place between January and February 2007. Both age classes were placed in identical 400 liter flow-through tanks and allowed to acclimatize for one week. The temperature in these tanks was maintained at 18°C and the fish were fed to satiation twice a day on Indian Ocean Aquafeed 2.2 mm or 1 mm dry pellets, depending on size class.

Experimental Design

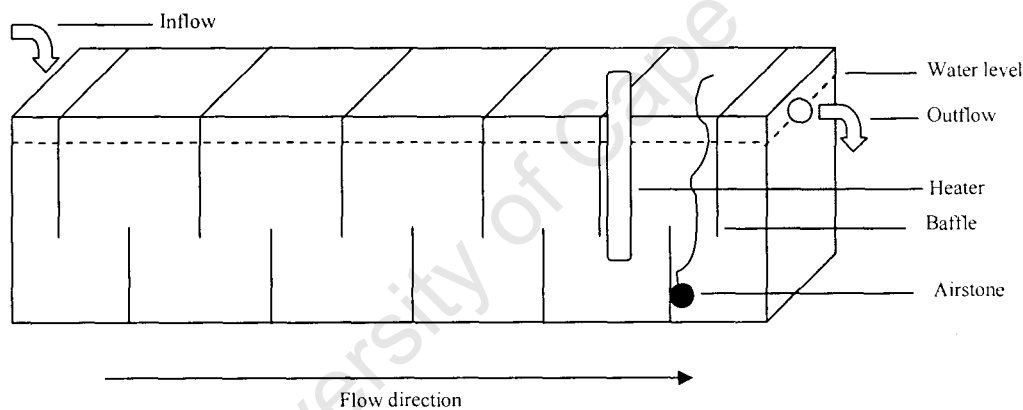


Figure 3: Horizontal temperature gradient tank design, showing compartments and flow direction. Heaters and airstones shown in this diagram were found in each compartment

Two identical horizontal temperature gradient tanks were set up in order to establish temperature preference. These glass tanks were similar to those used by Bernatzeder (2006), measuring 120x20x30 cm (Length x Width x Height). Each tank had 12 compartments separated from each other by partitions. These baffles were 16 cm long and were attached in an alternating manner from the top to the bottom of the tank to allow the movement of fish between the various compartments (Figure 3). The baffles were dark so as not to allow the fish to see into any other compartments, and as such, limit shoaling behaviour. A 300 W aquarium heater was placed in each compartment and these

were set so that the tank was heated from 16 – 21.5°C horizontally, with each compartment approximately half a degree warmer than the one before it. Trials were repeated and flow directions were reversed in each tank so as to eliminate any end-of-tank bias or directional bias.

The use of two separate tanks reduced any individual tank bias from affecting the results, and allowed for each experiment to be run twice, simultaneously. Lights were hung above the tanks and all the compartments were equally lit. Shade cloth covers were placed above the tanks to prevent jumping of fish and reduce the amount of light entering the tanks. Observer bias, which may have occurred due to sudden changes in light or activity outside of the tank area, was reduced by surrounding the tanks in a double layer of damp-proofing plastic. Six small slits were cut out of the inner layer for observational purposes and meant that the observer went virtually unnoticed by the fish and therefore would not scare the fish and cause them to move into another compartment.

Tanks were set up on a flow-through system where salinity remained constant at 35ppt. Incoming seawater first flowed into a 90 liter header tank where four 300 W aquarium heaters maintained the temperature at 16°C to ensure that any temperature fluctuations in the incoming water would not affect the experiment by causing changes in temperature between the compartments. From here the water flowed into each tank at a rate of 0.75l/min. A slow flow rate was chosen in both tanks so as to prevent any thermal mixing between chambers and eliminate flow rate as a possible factor in the spatial orientation and distribution of the juvenile silver kob (Kellogg and Gift, 1983). Airstones were placed in every second chamber to ensure oxygen concentrations did not become limiting throughout the tanks and to prevent stratification within the compartments. A photoperiod of 12L: 12D was maintained, with tanks lit from 6am to 6pm. During this time observations were done every four hours.

Trials

Prior to each trial, the fish were anaesthetized and weight (g) and total length (mm) of each fish were determined and standard deviation was calculated. The anaesthetizing agent used was 2-phenoxyethanol at a concentration of 0.1ml.l^{-1} for the first cohort and 0.2ml.l^{-1} for the second. Identical trials were performed on both the two-month-old ($0.23 \pm 0.04\text{g}$, 24.58 ± 2.84 mm TL) and the 15-month-old ($49.9 \pm 11.8\text{g}$, 178.1 ± 13.6 mm TL) fish, the only difference being the number of fish used in each experiment. Twelve 2-month-old fish were used per trial but the number was reduced to five 15-month-old fish due to their much larger size and their propensity to jump out of an over-crowded tank.

Initially, juveniles were placed in the tank without a temperature gradient so as to minimize stress and prevent temperature shock. The temperature gradient was then slowly allowed to establish over the course of a day, during which time the fish were allowed to acclimate. No observations were made during this time. The temperature trial was run for six days, one of acclimation and five during which observations were made. This follows from the experiment by Bernatzeder (2006) which showed that after six days, the distribution of the fish in the tank had stabilized, meaning that they had found their preferred temperature range.

Four observations were done each day at four-hour-intervals from 6am to 6pm. Each observation was repeated three times, at five minutes before the hour, on the hour and five minutes past the hour. These observations involved counts of the number of fish per compartment and were done three times to see if there was any movement of fish between the compartments. After each observation, temperature and dissolved oxygen measurements for each chamber were recorded using a YSI 30/10 temperature and salinity probe and a YSI 55 dissolved oxygen probe, respectively. This was to check if the temperatures remained constant throughout and that the dissolved oxygen concentration did not become limiting in the warmer chambers, owing to the fact that gas solubility decreases with an increase in temperature (Silberberg, 2000).

Fish were fed after every observation, with the food distributed evenly between the chambers. The tanks were siphoned at the end of every day to prevent the build up of left over food and fish faeces so as to maintain the water quality of the tanks.

In addition to the temperature preference trials, two isothermal control trials were also performed with each age class of fish. These control trials were identical in design to the thermal preference trials, except that the water in all the chambers was kept isothermal at a temperature of 18°C and therefore there was no temperature gradient. The purpose of the control trials was to determine whether the silver kob showed signs of shoaling despite the darkened baffles or if their distribution was random throughout the tank. The control trials were also used to establish whether any individual tank bias was affecting the results. If fish in one tank had shown a preference to one area of the tank in particular, we would know that it was due to a flaw in that particular tanks design and therefore would have kept that in mind when analyzing the temperature trial results from that tank.

Data Analyses

The residuals from each trial were calculated and used to test for normality using a normal probability plot and a Lilliefors test. Both showed that the data were not normally distributed and as a result, all statistical analysis was done using nonparametric statistics.

The nonparametric Kolmogorov-Smirnov test assesses the hypothesis that two samples were drawn from different populations. Unlike the parametric *t*-test for independent samples, or the Mann-Whitney U test, the Kolmogorov-Smirnov test tests for differences not only in the location of two samples, but is also sensitive to differences in the general shapes of the distributions in the two samples such as differences in dispersion, skewness etc. This test was therefore used to compare the distribution patterns of the fish in each tank as well as differences in number of fish observed per compartment and either reject or not reject the null hypothesis which was that there was no significant difference in fish distribution between the control trials and the temperature trials, and therefore that temperature does not affect the distribution patterns of the juveniles. This was done by

comparing the distribution of the individual trials to one another as well as the distributions of the control trials and the temperature trials and p-values were used to determine whether the observed frequencies were significantly different.

The results from the final day of the temperature trials, when the distribution had stabilized according to the preferred temperature range, were compared for trials one and two to determine whether there were any significant differences in temperature preference between the two size classes. This was done using the nonparametric Mann Whitney U Test. The conditions required to use this test were satisfied as the data were not normally distributed but were ranked or quantitative and the objective was to compare two populations with independent samples (Keller and Warrick, 2000). The test statistic (Z) was calculated and the p-value used to determine significance at the 95% confidence interval.

All data were analysed using the software packages Statistica 7.0 (Statsoft, Inc) and Microsoft Excel 2005. Sea surface temperature plots were generated using Giovanni (NASA) and satellite remote sensing data collected by MODIS.

Results

2 month old fish (1st Cohort)

The Kolmogorov-Smirnov test revealed no significant difference in distribution between tank 1 and tank 2 during the control trial ($p > 0.10$) and as a result, data from both tanks were added together for analysis. Figure 4 shows the number of times that fish occurred in each compartment for each day of the five day experimental period. A significant difference ($p < 0.01$) was, however, found between tanks 1 and 2 during the temperature trial and as a result the data for each tank are presented individually (Figure 5).

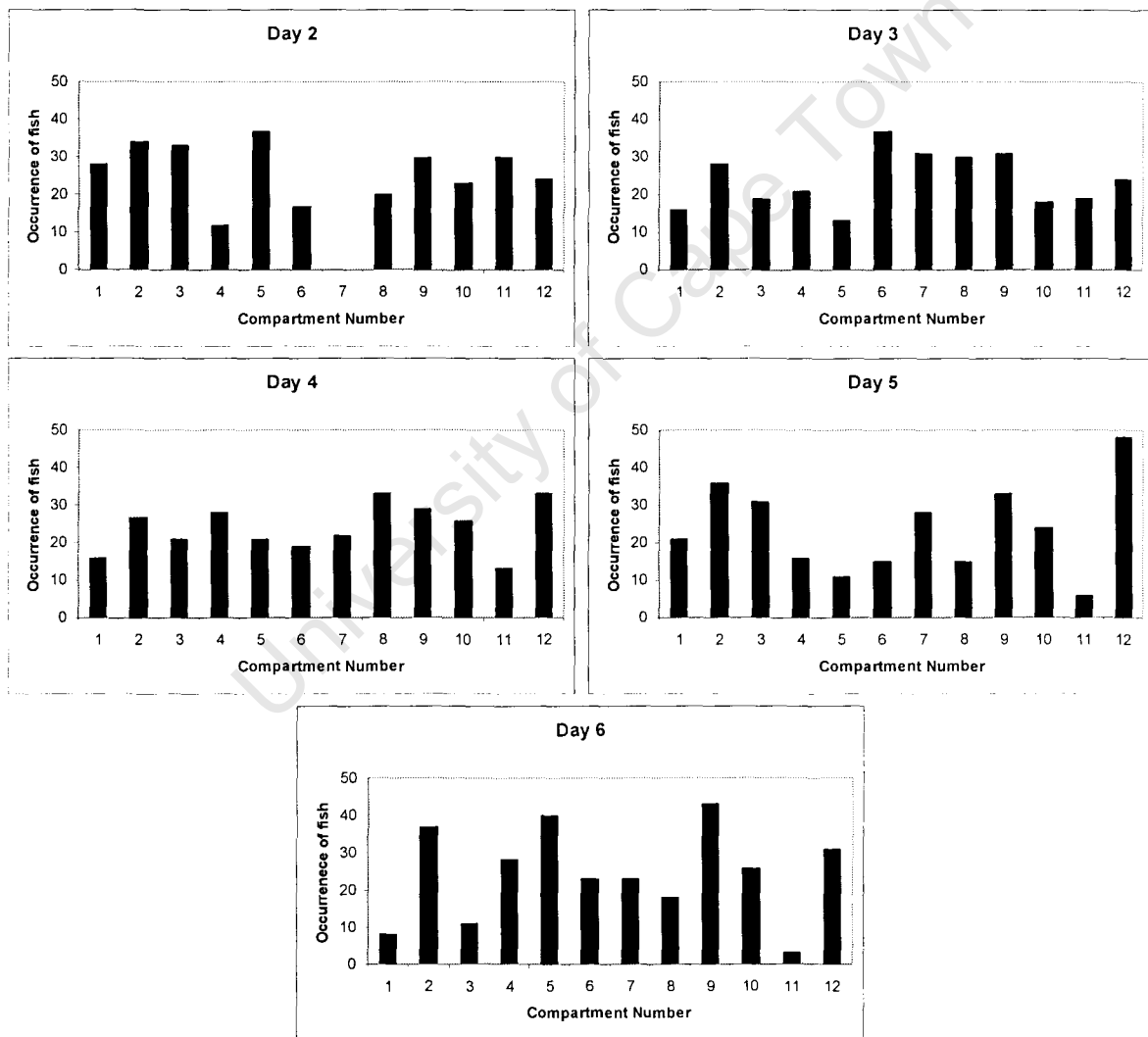


Figure 4: Summed data from tank 1 and 2 showing total number of first cohort fish observed in each compartment for each day of isothermal control trial 1 (no temperature gradient).

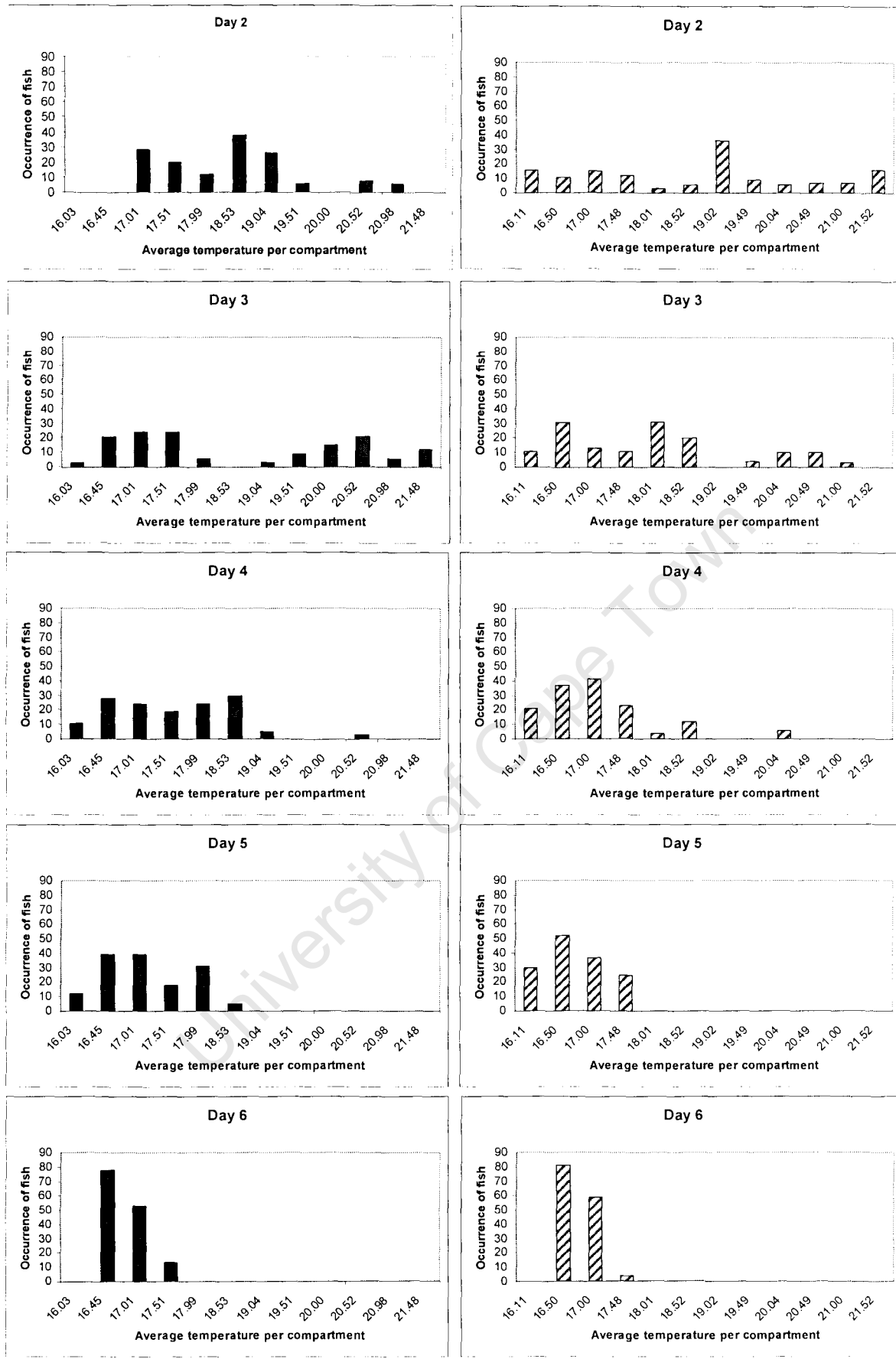


Figure 5: Frequency distribution showing total number of first cohort fish observed with respect to the average temperature per compartment per day for tanks 1 (left) and 2 (right) of temperature trial 1.

Differences in distribution were visible between the isothermal control trial data and the temperature trials. Figure 4 shows an even distribution of the observations over time, as fish remained evenly distributed throughout the compartments during the experimental period. There was no significant difference shown during the five days of the control trial ($p > 0.10$). However, in the temperature trial (Figure 5), there was a gradual migration of fish towards the first six compartments where average temperatures ranged from 16.03 to 18.53°C, whilst on the final day of the temperature trials, fish in both tanks 1 and 2 were only observed in compartments 2 – 4 where the average temperatures were 16.45 °C to 17.51°C for tank 1 and 16.50°C to 17.46°C for tank 2.

As temperatures fluctuated slightly within the compartments and between tanks from day to day and could not be kept constant, temperature and compartment were not considered the same variable but rather were analysed separately. Therefore, along with the occurrence of fish with respect to the average temperature per compartment as shown in Figure 5, the occurrence of fish with respect to the actual temperatures they were found at each day can be seen in Figure 6. This graph does not take into account the compartment number and distribution is based solely on temperature.

No significant difference was found between tanks 1 and 2 with respect to number of fish observed according to actual temperature ($p > 0.10$) and therefore the data from these two tanks were pooled (Figure 6). The trend is similar to that of the frequency distributions plotted against compartments, with fish observed within an initial temperature range of 15.8°C to 21.5°C on the first day of observation. This range of temperatures within which fish were distributed narrowed to a colder temperature range over time. By the final day of the experiment, fish were only observed between 16.3°C and 17.6°C with a modal temperature of 16.4°C.

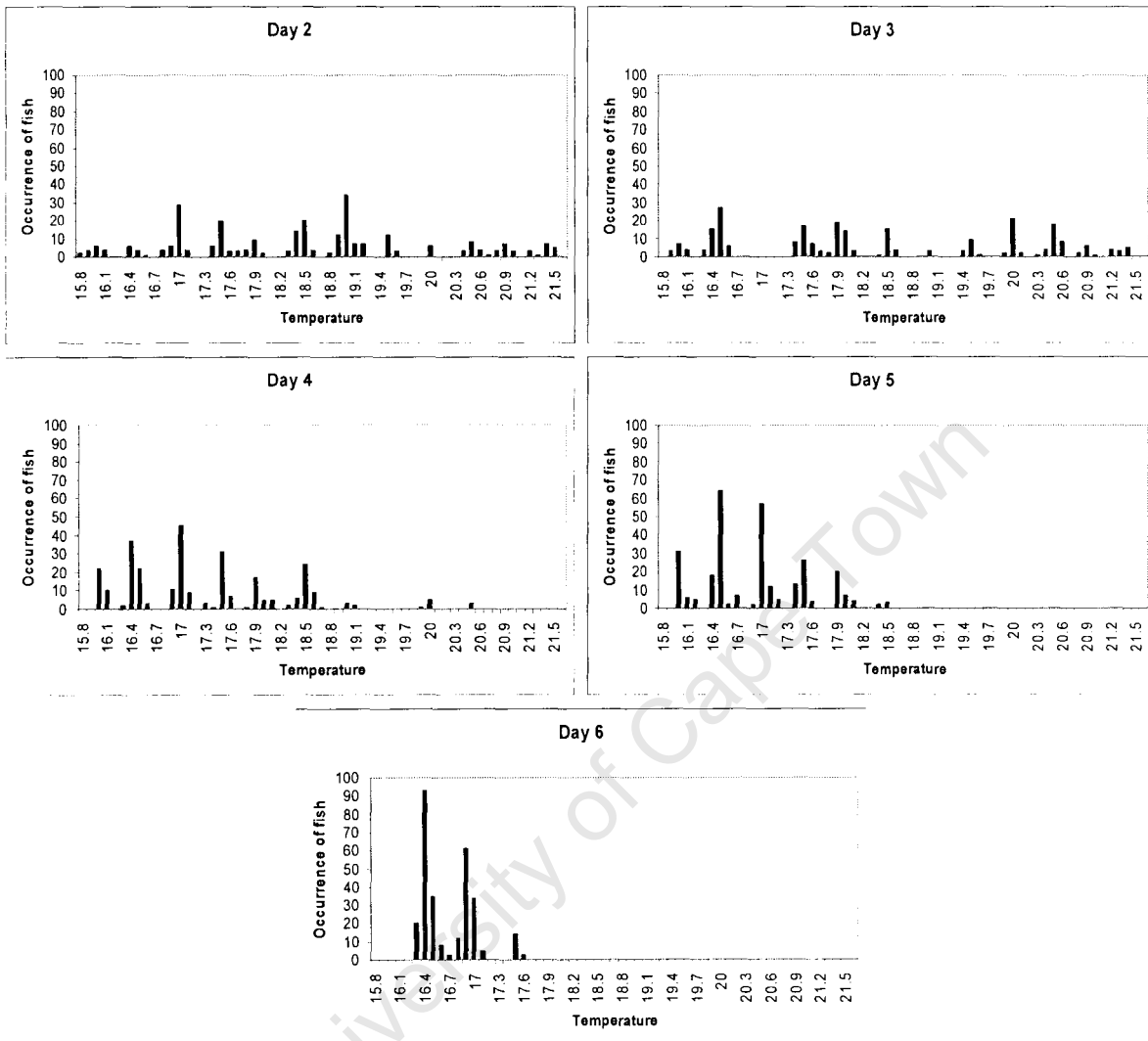


Figure 6: Summed data from tank 1 and tank 2 showing total number of first cohort fish observed according to actual temperature for each day of temperature trial 1.

15 month old fish (2nd Cohort)

There was no significant difference found between tanks 1 and 2 for the second control trial ($p > 0.10$) and the data from the tanks were therefore added together and displayed in one graph (Figure 7). As with the two-month-old fish (Figure 5), distribution of fish remained even throughout the experimental period with no migration of fish to any specific areas of the tank over time.

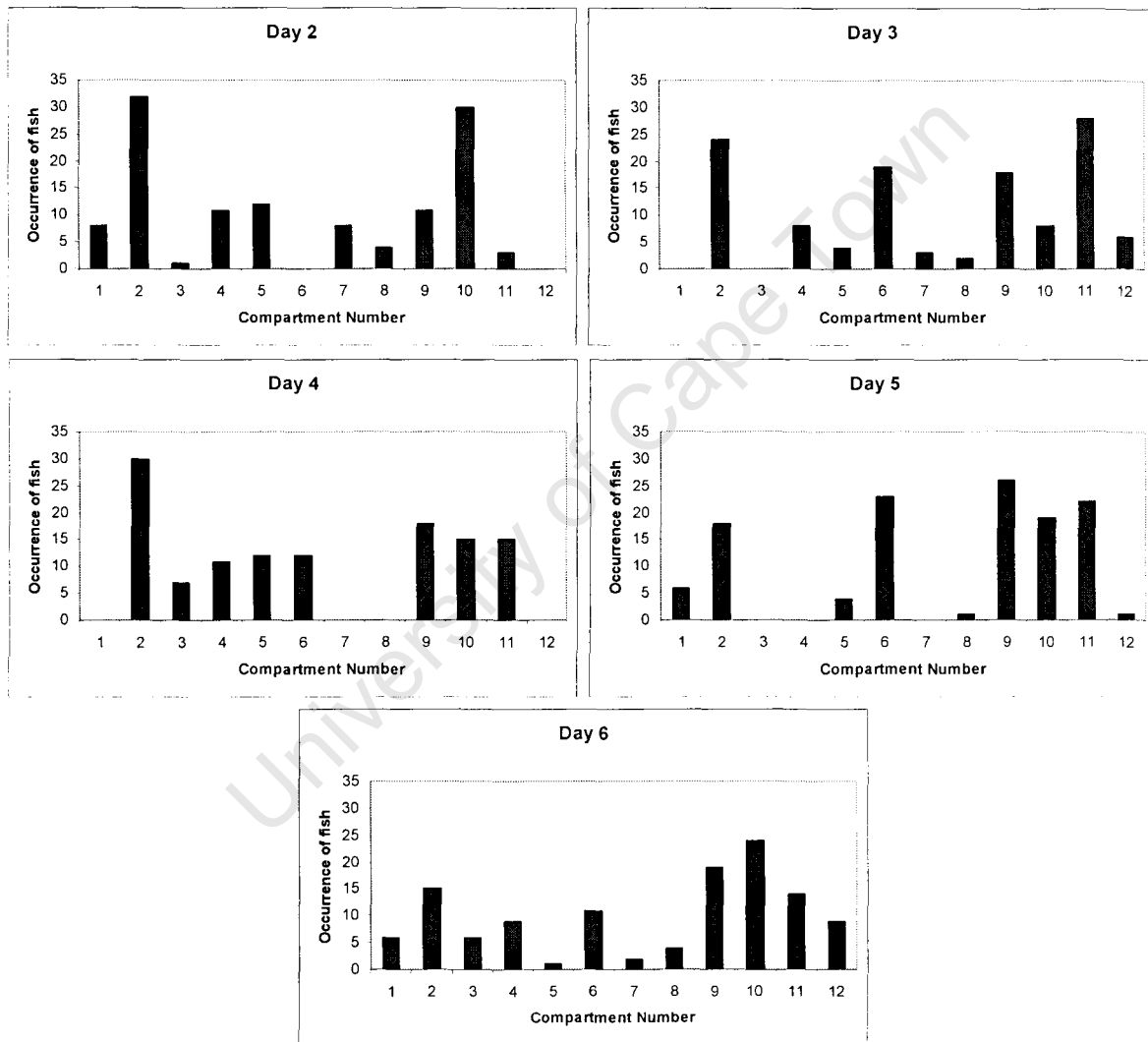


Figure 7: Summed data from tank 1 and 2 showing total number of second cohort fish observed per compartment for each day of control trial 2 (no temperature gradient).

The Kolmogorov-Smirnov test revealed a significant difference ($p < 0.01$) between tanks 1 and 2 during the temperature trial with the older fish. The data were therefore not pooled but analysed separately for each tank (Figure 7). As with Figure 5, the second cohorts also show a definite migration over time towards the first few compartments. On the final day of the trial, all the fish in tank 1 were distributed between compartments 3, 4 and 5 where the average temperatures ranged from 16.99°C to 18.10°C , while those in tank 2 were only observed in compartments 3 and 4 where average temperatures were between 17.04°C and 17.50°C .

As with the two-month-old fish, the temperature trial found no significant difference between tanks 1 and 2 with respect to the distribution of fish according to actual temperature ($p > 0.10$) and therefore the data from this trial were added and analysed together. Figure 9 shows the total number of fish that occurred at each temperature per day. The initial temperature where fish were observed was between of 16.5°C and 21.6°C on the first day of observation. This range narrowed over time and on the final day of the experiment, fish were only observed at temperatures between 16.9°C and 18.1°C with a modal temperature of 17.5°C .

The nonparametric Mann Whitney U Test revealed a significant difference ($p < 0.01$) between the data from the final day of temperature trials 1 and 2 ($Z = -12.73$) at the 95% confidence interval.

Dissolved oxygen during isothermal control trials was 8.04 ± 0.22 mg/l while during first cohort temperature preference trials it fell to 6.91 ± 0.51 mg/l with a maximum difference between the first and last compartments of 0.93 mg/l. During the second cohort temperature trials, the mean dissolved oxygen concentration was lower at 6.44 ± 0.47 mg/l while the maximum difference between the first and last compartments increased to 1.10 mg/l.

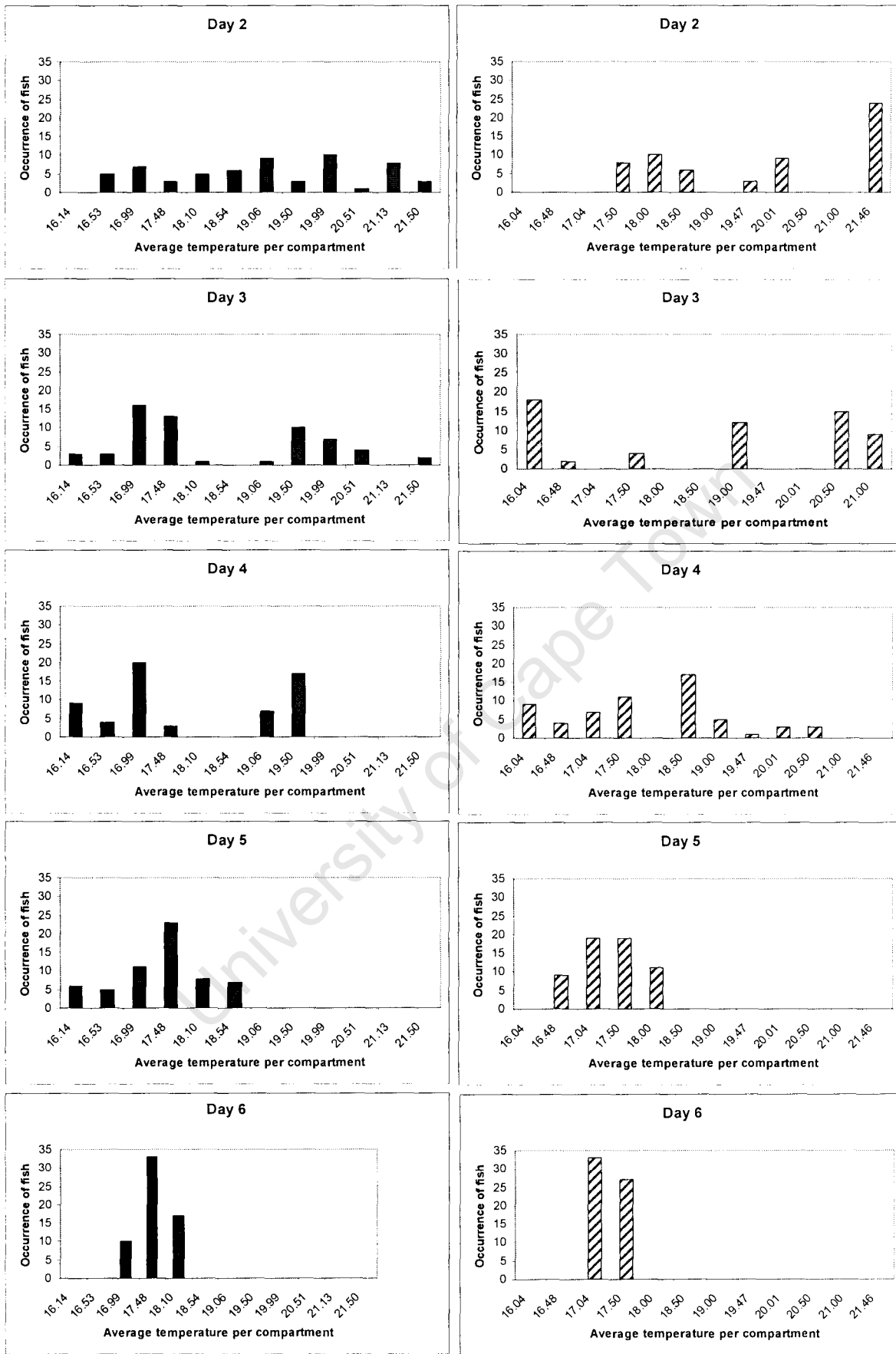


Figure 8: Frequency distribution showing total number of second cohort fish observed with respect to the average temperature per compartment per day for tanks 1 (left) and 2 (right) of temperature trial 2.

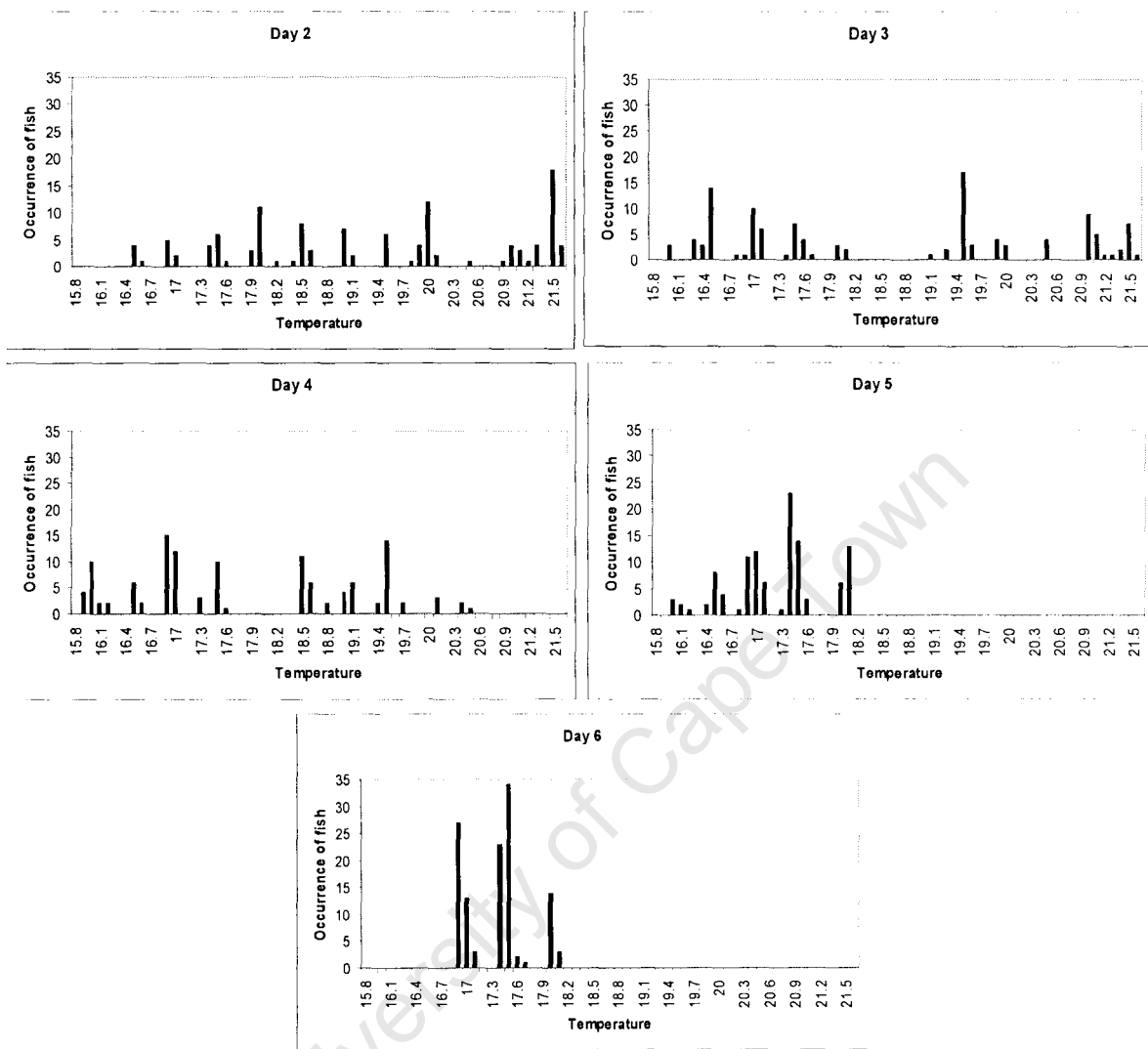


Figure 9: Summed data from tank 1 and tank 2 showing total number of second cohort fish observed according to actual temperature for each day of temperature trial 2.

Discussion

The isothermal control trials were used in an attempt to limit the affect that any individual tank or observer bias would have on the results as well as to determine whether any social interactions, such as shoaling behaviour, may have affected the results from the temperature trials. By not adequately comparing results from temperature gradient trials with those of isothermal control trials it is possible that the results gathered would be based on some behavioural or spatial preference, rather than a thermal one (Casterlin and Reynolds, 1982; Kellogg and Gift, 1983).

Although silver kob shoal in the wild (Griffiths, 1996), there were no signs of shoaling behaviour displayed by either cohort during the isothermal control trials as shown by the even distribution of fish throughout the compartments. Because of this it is safe to assume that the temperature trial data for both age classes were also not affected by shoaling behaviour, and therefore that results generated from these data are free of any shoaling or behavioural bias. This was attributed to the darkened baffles between the compartments that did not allow the fish to see into other compartments, although to be sure that this was the reason, another experiment with clear baffles would have to be undertaken. The control trials also showed that there was no individual tank bias which could affect the results as no significant difference was found between the tanks in either of the trials. This means that fish did not react differently in one tank, but followed the same distribution patterns regardless of which individual tank they were in.

By comparing the frequency distributions of the isothermal control trials and the temperature trials for the first and the second cohorts, it is immediately evident that the distribution of fish throughout the compartments during the temperature trials is very different to that of the control trials. During the control trials, fish remained evenly distributed throughout the compartments, throughout the six-day experimental period, with no significant differences between the days. The occurrence of fish per compartment in the temperature trials however, showed that although both cohorts remained evenly distributed throughout the compartments for the first two days of observation, a definite

migration could be seen between day 4 and 6 towards specific compartments finally settling in 2 or 3 compartments on the last day. Results from the first temperature trial show that on the final day the three-month-old fish had settled between compartments 2 and 4 in both of the tanks, where temperatures ranged between 16.45°C and 17.51°C, while during the second trial with the 15-month-old fish, they occurred between compartments 3 and 5 in tank 1 and between compartment 3 and 4 in tank 2, with temperatures ranging from 16.99°C to 18.10°C and 17.04°C to 17.50°C, respectively. This is significantly different ($p < 0.01$) from the results of the control trials and as a result we are unable to accept the null hypothesis and must therefore argue in favour of the alternate hypothesis, which is that temperature did have an effect on the distribution of the juvenile silver kob.

The pooled data from the temperature trials, showing fish distribution with respect to actual temperature rather than compartment, indicated that both cohorts migrated to the cooler temperatures over time. As we have determined that shoaling behaviour and individual tank bias had no effect on the final results by way of the control trials, it is evident that this observed migration is a behavioural response to the temperature gradient. The final preferred temperature range for the first cohort fish was between 16.3°C and 17.6°C while the temperatures preferred by the second cohort were significantly warmer ($p < 0.01$), with the preferred range lying between 16.9°C and 18.1°C. These results are reasonable as they fall within the natural temperature range of silver kob. The grouping of all the fish into a few compartments was similar to the trend found by Bernatzeder (2006) where dusky kob juveniles were shown to migrate towards their preferred temperature over the course of the experimental period and eventually settled in their zone of final preferendum on the sixth day.

As this is the final temperature preferendum rather than the acute temperature preferendum (Fry, 1947) and as it was only established once the distribution of the fish had stabilized, the preferred temperature range was not dependant on the acclimatization temperature and although the preferred range of both cohorts fell near to the acclimatization temperature of 18°C, this was merely a coincidence, and does not imply

that the results were affected by the acclimation temperature. The final temperature preference is species specific and not based on any thermal history (Fry 1947, Deacon 1997, Birtwell *et al.*, 2003).

Oxygen levels remained high throughout the trials and fish displayed no signs of distress, which would be expected if oxygen levels became limiting. Therefore, dissolved oxygen did not have an effect on the distribution of the fish throughout the tank. The differences in dissolved oxygen concentration between the first and last compartments during the temperature trial can be explained by the fact that gas solubility decreases with increasing temperature (Silberberg, 2000). Dissolved oxygen concentrations during the second cohort trials were lower than those in the first cohort trials, but this is explained by the difference in size between the two age groups, the larger cohorts requiring more oxygen for their physiological processes.

The results therefore indicate that juvenile *Argyrosomus inodorus* have a preferred temperature range and that this preferred range is significantly different between the two age classes, with the second cohort preferring slightly warmer temperatures than the first. Adult silver kob are migratory species (Griffiths, 1996; Kirtchner and Holtshausen, 2001) that are found inshore in summer (<60m) dispersing further offshore in winter in response to oceanographic patterns (Griffiths, 1997). This could be due a behavioural response to the changes in water temperature around the coast. On the west coast of southern Africa, longshore southerly winds blow along the coast during summer pushing the surface waters offshore and causing cold, nutrient-rich Intermediate water from 300m deep to be upwelled and brought to the surface. This means that the water off the west coast is colder during the summer than it is in winter. If the older fish also prefer cold water, this would explain why they migrate offshore in winter as the water inshore would be warmer than it had been in summer.

The hypothesis that silver kob juveniles have a preferred temperature range was supported by this study as was the fact that this preferred temperature changes with age.

There are a few shortcomings of this study that need to be addressed, firstly that of the size of the tanks. The second cohort fish had a mean length of 178.1 ± 13.6 mm TL and the length of the compartments was only slightly longer than fish length. Thus, not more than three fish could fit into a compartment at once. Although the fish did not seem to display any signs of stress as a result of this, it may have had an influence the final temperature preference results. Also, only five of the second cohort fish could be placed in each tank due to space limitations, it would be advisable for future studies of this nature to use larger tanks. Apart from this it was impossible to eliminate all of the observer bias as some disturbances could not be avoided during the observations, such as movement behind the plastic, or an increase in noise as plastic was moved. The tanks also needed to be siphoned daily and temperature and dissolved oxygen concentration had to be measured after every observation, which disturbed the fish and may also be seen as a shortcoming. The survival rate was 100% during the study.

Previous studies of this nature have shown a good correlation between the preferred temperature of a species and the temperature required for optimal growth (Jobling, 1981, Kellogg and Gift, 1983). If this turns out to be the case for silver kob as well it may cause some logistical problems for the aquaculture industry that is already established up the west coast of South Africa as it may not be economically viable to heat the water, which is usually between 14 and 15°C in that area, and keep it at the optimal temperature for the best growth rates. This may limit the number of locations where silver kob can be cultured economically.

Recommendations

As the results indicate that juvenile silver kob have a preferred temperature range, and that this range changes with age, optimal conditions for growth must now be determined. While studies have shown that the final preferred temperature often corresponds with the temperature required for optimum growth, growth trials will still need to be conducted, to determine whether this is also the case for silver kob. The results from this study may be

used as a starting point for these trials, although it would still be necessary to test a wide range of temperatures.

Along with studying the effect of temperature on growth, studies would need to be designed in order to determine the effects of other controlling and masking factors such as pH and salinity which may stunt growth even if temperature is kept at the optimal levels. Stocking density is also very important and needs to be taken into account and studies will need to be designed to test for its optimal levels. Dusky kob or mulloway (*A. japonicus*) farms in Australia have shown that due to their natural shoaling tendencies, the best productivity is achieved at high stocking densities (15kg/m³) (Mulloway Factsheet) and while this is a different species, it shows that the optimum levels of many environmental variables must be understood before commercial culture becomes a possibility, and not only the optimum temperature. Once the effects that these and other environmental factors have on fish growth is more fully understood it may be necessary to investigate the interactions between them and determine what is the best combination of factors that will achieve optimal growth .

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