Spatial Variability of Recent Otolith Growth and RNA Indices in Pelagic Juvenile Diaphus kapalae (Mycophophidae): an Effect of Flow Disturbance near an Island?

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Abstract. In February 1993, the pelagic juvenile myctophid Diaphus kapalae was sampled with a neutron net in the southern Coral Sea in a region of flow disturbance north of Cato Reef and to the east in the free ocean (northerly flow at 30 cm s⁻¹). There was no significant difference in the size (11-16 mm SL) or age (45-74 days after hatching) between the two regions. Recent growth indices derived from the width of the peripheral daily growth increments (1-10 µm each) revealed enhanced otolith growth 38 km downstream and up to 4 days before capture. No significant difference was found for times longer than a week before capture, consistent with fluctuation of the wake indicated from current-meter data. Daily increment formation was confirmed by marginal incremental analysis. Recent otolith growth was correlated with the RNA content adjusted by dry weight, which also revealed significantly higher condition in the wake region. Recent growth was correlated with microzooplankton biomass, recorded with an optical plankton counter.

Introduction

The condition, or health, of larval and juvenile fish is a means of assessing the significance of oceanographic features for fish populations during the critical planktonic stage of early life history. Flow disturbance occurs downstream of oceanic islands, generated by each island acting as a stirring rod within the predominant circulation (e.g. Barkley 1972; Emery 1972; Heywood et al. 1990; Boehtelt et al. 1992; Boehtelt and Mundy 1993). Nutrient-laden deep water may be drawn into the euphotic zone, stimulating in one example a fivefold increase in the biomass of chlorophyll (Simpson et al. 1982). Horizontal characteristics of this flow disturbance may include increased phosphate concentrations downstream (Mackey et al. 1987), enhanced chlorophyll concentrations (Simpson et al. 1982) and an altered distribution of zooplankton (Hamner and Haury 1981). Alternatively, little or no effect may be observed (Dandowenhna and Charpy 1985; Le Borgne et al. 1985; Rogers 1994), possibly owing to the variety of oceanographic conditions and spatial/temporal scales (Le Borgne et al. 1985; Gowan and Cavena 1994).

Vertically, upwelling is characterized by an upward doming of the thermocline (by over 60 m in Heywood et al. 1990). The thermocline is associated with the nutrient and increased chlorophyll concentrations (Furnas and Misuth 1986) as well as increased abundance of larval fish (Loeb 1979).

Upwelling due to flow disturbance can extend over an area some 20 times the island area (Simpson et al. 1993). This effect, along with other sources of new nutrient (nutsock, and endo-geothermal upwelling, Rougerie et al. 1992), may be crucial to the fishing and tourist industries of many islands in the South Pacific, as this is the only source of new production around many isolated islands situated in depths >1000 m. Other sources of new nutrient such as continental shelf waves, tidal inflows and geostrophic suction occur at scales of 100-1000 km (Griffin and Middleton 1986; Nof and Middleton 1989), which cannot generate upwelling around small steep-sided atolls. Studies of adult fish foraging (Rogers 1994) and of fishing activity in island wakes (Bolzanes 1981) have indicated the importance of flow disturbance, but no study has examined the trophic significance of island wakes for larval fish.

Do the elevated concentrations of chlorophyll observed in island wakes ultimately contribute to the condition of larval fish? Many indices have been used to determine nutritional condition in larval fish, involving morphological (e.g. Ehrlich et al. 1976), histological (e.g. Ehrlich et al. 1976; Theilacker 1986; Martin and Wright 1987) and biochemical techniques (e.g. Buckley 1984; review in Ferron and Leggett 1994). The RNA-DNA condition index adjusts the amount of protein synthesis, as indicated by the amount of RNA, by the size of the larva, as indicated from the number of cells and the amount of DNA. In the form of a ratio, this index can discriminate starved larvae from fed larvae within 3-4 days (Martin and Wright 1987; Westerner and Holt 1994) and has been used to discriminate between gaidid larvae from stratified and mixed conditions on Georges Bank (Buckley and Lough 1997).

Recent study growth increments of the otolith are another method of assessing larval growth and condition in relation to prey availability in the ocean (e.g. Gwioni et al. 1985; 1232-14/09/90/02272805.00)
Bailey 1985; Suthers et al. 1989). Although otolith growth is considered to respond conservatively to starvation (Milichon and Chou 1990; Milich and Chou 1992), the width of recent growth increments in larvae can respond within days of dietary change (Giovoni 1985; Eckelbarger and Key 1987; Bailey and Stehr 1988; Maillot and Checkley 1990; Suthers and Sundby 1993). Furthermore, recent growth increments and RNA-DNA measures were found to be correlated in larval plaice (Hovenkamp 1990; Hovenkamp and Witte 1991).

The aim of this study was to compare the condition indices, derived from RNA and recent otolith growth, of pelagic juvenile myctophids between an area of flow disturbance in the lee of an island and the free stream. The condition indices were intercompared and correlated with zooplankton biomass, determined with an optical plankton counter.

Materials and Methods

Study Area

Cato Reef is an isolated reef in the southern Coral Sea (23°3′.155°E), approximately 350 km off the coast of Rockhampton, Queensland. Rising from a depth of 2000 m to the surface over a horizontal distance of 30 km or less, the reef itself is approximately 10 to 15 km at the 100-m isobath and breaks the surface in two places (Fig. 1). The nearest reef is Weep Reef, approximately 30 km north-east. During 16-21 February 1993 a northward flow of approximately 30 cm s⁻¹ was observed with an acoustic Doppler current profiler (ADCP). It resulted in a region of flow disturbance that extended in at least 300 m depth (limn of ADOP). This region extended 30 km north of the island (Fig. 1). The wake was also manifested by an upward Dowelling of the northern end by 40-60 m. Currents were probably influenced by the passing of Tropical Cyclone ‘Oliver’, which was located for two days about 300 km north-west of Cato, with winds up to 80 km. Full physical and biological descriptions of the island wake are in preparation.

Two transects of three stations each were established: one perpendicular to the flow (eastern transect, Stations E1, E2 and E3) and the other through the wake region (northern transect, Stations N1, N2 and N3) (Table 1, Fig. 1). Water temperatures averaged 25.7°C (range 25.6-25.8°C) between 5 and 25 m depth during the investigation. Each transect was sampled in a night, with replication of the middle station before dawn. Sampling was replicated over three nights for each transect (Table 1).

Pelagic juvenile myctophids were captured in replicated tow nets at each station with a square-mouthed plankton net (mesh area 75 cm²).

<table>
<thead>
<tr>
<th>Table 1.</th>
<th>Description of stations and transects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date in February 1993. Latitude (°), Longitude (°), bathymetry at station (m), distance from 100-m isobath (km) and mean temperature (°C) from 5 to 25 m.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>February</th>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Bathymetry</th>
<th>Distance</th>
<th>Temp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>16, 19, 21</td>
<td>E1</td>
<td>23°25′</td>
<td>155°48′</td>
<td>1087</td>
<td>6.2</td>
<td>25.7</td>
</tr>
<tr>
<td>E2</td>
<td>23°23′</td>
<td>155°57′</td>
<td>1422</td>
<td>14.6</td>
<td>25.8</td>
<td></td>
</tr>
<tr>
<td>E3</td>
<td>23°22′</td>
<td>155°51′</td>
<td>1850</td>
<td>17.5</td>
<td>25.8</td>
<td></td>
</tr>
<tr>
<td>17, 18, 20</td>
<td>N1</td>
<td>23°15′</td>
<td>155°55′</td>
<td>294</td>
<td>5.4</td>
<td>25.6</td>
</tr>
<tr>
<td>N2</td>
<td>23°05′</td>
<td>155°55′</td>
<td>1441</td>
<td>15.8</td>
<td>25.6</td>
<td></td>
</tr>
<tr>
<td>N3</td>
<td>22°59′</td>
<td>155°52′</td>
<td>1744</td>
<td>17.7</td>
<td>25.8</td>
<td></td>
</tr>
</tbody>
</table>

mesh size: 300 μm). A flowmeter was situated in the mouth of the net, and all tows were taken at 1-2 m s⁻¹ for 5-8 min. Myctophids were jet black in colour (range 11–16 mm standard length, SL; see Table 2) and were easily separated from the zooplankton. They were stored either in liquid nitrogen or in 1:5 v/v of 95% alcohol (onshore analysis). Larvae were not present or were sufficiently abundant for all 18 night stations combined, and replicate night stations were therefore pooled by station for condition analyses (see Tables 2 and 3).

During each tow, an optical plankton counter (OPC, Sprules et al. 1992) was deployed over the stern, which provided zooplankton biomass abundance in one size range between 300 and 2500 μm equivalent spherical diameter (esd), roughly equivalent to the retained 300 μm mesh size. Data were restricted to the 5-25 m depth range for comparison with the neutron net tows.

Otolith Analyses

Each fish was measured (standard length, SL), then dried in a 60°C oven for 48 h and cooled in a desiccator for 30-60 min before being weighed on a Cahn electrobalance to the nearest 0.001 mg. Sagittal otoliths were extracted under polarized light, affixed to glass slides with low-staining glue, and polished almost to the mid plane with fine-grade commercial sandpaper and 12-μm lapping film (Hersom and Casparis 1993). The otoliths were then soaked in a 2% NaOH, rinsed and stained with 1% silver nitrate, then stained from the other side to the mid plane. The air-dried polishes were necessary to penetrate the metamorphic zone (Gjermoe 1983; Gjermoe 1991a), to expose the laval increments. Otoliths were examined with the 1400 and 440 objective of a microscope, and measured with the aid of a video system and digitizer connected to a Macintosh computer (Anderson and Moenness 1998).

Fig. 1. Cato Reef, showing current vectors from the ADCP in the 49-m depth bin, using 30-mm integrated profiles, during 15–16 February 1993 (IP Courts and J. H. Multnom, personal communication). Maximum vector size is 74 cm s⁻¹. A northwest flow averaging 30 cm s⁻¹ is evident through the eastern transect, with flow disturbance to the north and north north-west. Exposed reef is denoted in black, surrounded by the 50-m, 500-m, 1000-m and 2000-m isobaths. A, Andros current meter; B, plankton sampling stations.
Table 2. Summary of otolith information subjected and sample sizes (N) of D. kapulola at each station

<table>
<thead>
<tr>
<th>Station</th>
<th>N</th>
<th>SL (mm)</th>
<th>DW (g)</th>
<th>N_{wet}</th>
<th>N_{tot}</th>
<th>L_{wet} (mm)</th>
<th>T_{wet} (days)</th>
<th>G</th>
<th>N_{obs}</th>
</tr>
</thead>
<tbody>
<tr>
<td>BI</td>
<td>17</td>
<td>13.6 (0.2)</td>
<td>5.65 (0.27)</td>
<td>15</td>
<td>96.0 (8.8)</td>
<td>40 (10.9)</td>
<td>60 (1.6)</td>
<td>0.228 (0.081)</td>
<td>11</td>
</tr>
<tr>
<td>B2</td>
<td>16</td>
<td>13.4 (0.1)</td>
<td>5.00 (0.16)</td>
<td>15</td>
<td>8.9 (0.5)</td>
<td>14 (0.4)</td>
<td>57 (1.0)</td>
<td>0.234 (0.085)</td>
<td>15</td>
</tr>
<tr>
<td>E3</td>
<td>9</td>
<td>13.1 (0.2)</td>
<td>5.42 (0.30)</td>
<td>7</td>
<td>8.0 (0.6)</td>
<td>37 (1.0)</td>
<td>56 (1.1)</td>
<td>0.234 (0.094)</td>
<td>6</td>
</tr>
<tr>
<td>N1</td>
<td>1</td>
<td>10.2</td>
<td>5.14</td>
<td>1</td>
<td>7.0</td>
<td>37</td>
<td>52</td>
<td>0.255</td>
<td>0</td>
</tr>
<tr>
<td>N2</td>
<td>42</td>
<td>12.2 (0.1)</td>
<td>5.01 (0.12)</td>
<td>36</td>
<td>6.9 (0.3)</td>
<td>39 (0.4)</td>
<td>57 (0.6)</td>
<td>0.255 (0.071)</td>
<td>24</td>
</tr>
<tr>
<td>N3</td>
<td>22</td>
<td>10.0 (0.1)</td>
<td>5.95 (0.26)</td>
<td>21</td>
<td>8.2 (0.7)</td>
<td>36 (0.7)</td>
<td>51 (1.1)</td>
<td>0.241 (0.065)</td>
<td>17</td>
</tr>
<tr>
<td>Total</td>
<td>107</td>
<td>13.2 (0.1)</td>
<td>5.46 (0.08)</td>
<td>95</td>
<td>8.0 (0.3)</td>
<td>38 (0.3)</td>
<td>70 (0.5)</td>
<td>0.232 (0.082)</td>
<td>71</td>
</tr>
</tbody>
</table>

Note: SL = standard length (mm); DW = mean wet weight (g); N_{wet} = number of otoliths measured for wet weight; N_{tot} = average number of post-larval increments measured for recent growth indices; L_{wet} = average total length of larva increments; T_{wet} = average total number of increments; G = mean overall growth rate (mm day^{-1}); N_{obs} = number of otoliths measured for otolith growth history. Numbers in parentheses are standard errors.
increased rapidly after 3 weeks until the beginning of the brown, metamorphic zone around Day 38 after hatching (Fig. 3). At Day 38, SL was on average 10.8 mm (range 8.4–11.6 mm), based on the range in radii at Increment 18: SL = 8.234 + 0.017*radius (r = 0.71, r² = 0.31). Ages ranged between 45 and 77 days after hatching, and overall growth rates were about 0.1 mm day⁻¹ (Fig. 4).

Post-metamorphic Zone

There were 3–16 clear increments in the post-metamorphic zone (PMZ), which were easily measured in the rostrum region (Fig. 2a). Marginal increment analysis showed these PMZ increments to be formed daily. The width of the marginal increment, as a percentage of the penultimate increment, was linearly related to the time of sampling over the 8 h of complete darkness (Figs 2b, 2c, and 5). At 1600 hours, approximately 20% of the penultimate increment width was formed, including the narrower, dark, protein-rich discontinuous zone (Fig. 2b).

By 0300 hours nearly 100% of the penultimate increment was formed, by completing the broader, white, translucent zone (Figs 2c and 5).

The width of recent growth increments in the rostrum area was used as an index of recent somatic growth, based on the linear relationship of the otolith diameter at the rostrum with SL (diameter = 66.67 + 36.51*SL, r = 0.98, r² = 0.31). Therefore, a change in the width of recent growth increment is proportionally equivalent to a change in SL.

The average width of the peripheral increments was linearly related to the total number of increments in the PMZ (Fig. 6a), excluding those larvae with ≤4 PMZ increments. Thus, on average, increment width increased over the first three PMZ increments before declining. By excluding fish with ≤4 PMZ increments, the average width

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**Fig. 2.** (a) Lateral view of a polished sagitta from *Diplocaulus apiculatus*, showing major landmarks and zone for measurement. G, growth history zone; R, ridges (250 µm); A, anterior edge of otolith; E, edge of otolith; P, penultimate increment formed; Scale bar, 500 µm. (b) Marginal increment formation in sagitta from a specimen caught at 0900 hours, with 22% of penultimate increment formed. Scale bar, 100 µm. (c) Marginal increment formation in sagitta from a specimen caught at 0100 hours, with 90% of penultimate increment formed. Scale same as in (b). (d) Dorsal view of the sagitta in Fig. 2a, showing (from left to right) the larval growth increments, the formation of accessory primordia, and the metamorphic zone. Arrow indicates the study of rug structure, with larger marks on the metamorphic zone, and the otolith growth increments of the post-metamorphic zone. Scale same as in (b).
of increments was linearly related to number of increments in the PMZ for Days 1 and 2 (n = 87, Fig. 6a), Days 3 and 4 (n = 81, Fig. 6b) and Days 5 and 6 (n = 53, Fig. 6c) before capture. There was no significant difference in slopes between the eastern and northern stations (ANCOVA, P > 0.3), but the intercepts were significantly greater by 0.8 ± 1.3 μm in the northern stations for Days 1 and 2 and Days 3 and 4 (P = 0.00) and 0.05 respectively.

An individual residual-based index was generated from the overall regression on each day (Fig. 6), as the regression slopes between transects were found to be homogenous.

The non-linear section at ≤4 PMZ increments was excluded as noted in Fig. 6. Recent growth on Days 1 and 2 before capture was significantly greater at Station N3 than at Stations E1 and E2, and was significantly greater at Station E3 than that at E2 (1-way analysis of variance or ANOVA, Tukey’s test, P < 0.02, Fig. 7a).

Recent growth on Days 3 and 4 before capture was the same at Stations E3 and N3 and significantly greater than at E1 and E2 (Tukey’s test, P < 0.02, Fig. 7b). Recent growth on Days 5 and 6 before capture was not significantly different at any station (Fig. 7c, P = 0.49).

![Figure 3](image_url)  
Fig. 3. Average increase in increment width (μm) in *D. lapidus* with respect to increment number (days) from hatching at each station.

![Figure 4](image_url)  
Fig. 4. Standard length (SL, mm) plotted against number of growth increments in *D. lapidus*. SL = 10.85 + 0.04age (n = 95, r² = 0.08).

![Figure 5](image_url)  
Fig. 5. Marginal increment formation in *D. lapidus* over 8 h from 1900 to 0700 hours, plotted as a percentage of the penultimate increment. Individuals are derived from all collections.
The recent ontological growth on Days 1 and 2 before capture was significantly correlated to the rooplandroon biomass, as determined by the OPC, in the medium size range (1000-2500 μm equivalent spherical diameter, r = 0.78, Fig. 8), as it also was on Days 3 and 4 (r=0.50). Greater concentrations of medium-sized particles tended to occur at the N stations (Fig. 8). There was no significant correlation on Days 3 and 6 (r = 0.10). Recent growth was not correlated to the concentration of small particles (300-1000 μm esd).

RNA-Dry Weight

The average sizes of Diaphus capulare used in the RNA-DNA analysis were similar to the average sizes used for otolith analyses (within 2.6 mm SL, Tables 2 and 3). The average RNA-DNA ratio at each station ranged between 0.51 and 0.60 (except the one individual at N1) and showed no trend within or between transects (Table 3). The amount of RNA was related to DNA by: RNA = 28.04 + 0.27*DNA, n = 61, r² = 0.31.

Fish from the northern stations had significantly more RNA per milligram of dry weight than did those from the eastern stations (ANOVA: slopes, P < 0.06, intercepts, P = 0.04). Therefore, a common regression was fitted (Fig. 9), and the residuals from this relationship were used as individual condition indices and to calculate station averages. The average RNA-DW index of fish was significantly greater at Station N3 than at Station E3 (Tukey's w4, P = 0.02), whereas the other comparisons were not significantly different (ANOVA, P > 0.18, Fig. 9).

In contrast to the otolith index, the mean RNA-DW index for each sample showed no significant relationship to the concentration of medium-sized particles (r = 0.04).

The biochemical and otolith indices on Days 1 and 2 (derived for separate individuals from the same sample) for

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**Fig. 6.** Average width (μm) of increments plotted against the number of otolith postnatal growth increments. (a) Days 1 and 2 before capture: width = 184.41 - 0.09*incmments, n = 87, r² = 0.31, for total PMZ increments < 6; (b) Days 3 and 4 before capture: width = 15.70 + 0.66*increments, n = 61, r² = 0.31, for total PMZ increments < 6; (c) Days 5 and 6 before capture: width = 15.28 + 0.45*increments, n = 53, r² = 0.19, for total PMZ increments < 8.

**Fig. 7.** Recent growth indices, derived from the residuals of Fig. 6 and excluding the non-linear portion of (a) Days 1 and 2 (increments < 6), (b) Days 3 and 4 (increments < 6), and (c) Days 5 and 6 (increments < 8). The one fish from Station N3 was excluded. Error bars are standard error.

**Fig. 8.** Average recent growth index (x days 1 and 2 before capture for all stations and weights plotted against ammonium biomass recorded with the optical plankton counter in the medium size range (1000-2500 μm), number per T/L, r = 0.78). Station labels on different graphs are beside each data point. Error bars are standard error.
Table 3. Summary of RNA:DNA information used in D. kapalae

<table>
<thead>
<tr>
<th>Station</th>
<th>n</th>
<th>SL (mm)</th>
<th>DW (mg)</th>
<th>RNA:DNA</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>11</td>
<td>13.1 (0.2)</td>
<td>74.6 (5.3)</td>
<td>0.60 (0.04)</td>
</tr>
<tr>
<td>E2</td>
<td>12</td>
<td>14.6 (0.5)</td>
<td>76.6 (0.9)</td>
<td>0.54 (0.04)</td>
</tr>
<tr>
<td>E3</td>
<td>6</td>
<td>14.1 (0.7)</td>
<td>75.5 (0.8)</td>
<td>0.51 (0.04)</td>
</tr>
<tr>
<td>N1</td>
<td>1</td>
<td>15.5 (5.8)</td>
<td>8.2 (2)</td>
<td>0.39</td>
</tr>
<tr>
<td>N2</td>
<td>17</td>
<td>13.9 (0.3)</td>
<td>7.0 (0.5)</td>
<td>0.59 (0.04)</td>
</tr>
<tr>
<td>N3</td>
<td>15</td>
<td>15.1 (0.3)</td>
<td>4.7 (0.4)</td>
<td>0.58 (0.05)</td>
</tr>
</tbody>
</table>

Fig. 9. Relationship of RNA (µg per fish) to dry weight (DW, mg) for D. kapalae (RNA = 16.2×5.09/DW, n = 62, r² = 0.59).

Fig. 10. Average residuals from the regression of RNA on dry weight (DW) (Fig. 9) for each station for D. kapalae. The one fish from Station N1 was excluded. Error bars are standard error.

Discussion

Overall, D. kapalae moved significantly greater recent otolith growth and greater RNA per milligram of dry weight at the freshwater downstream station (N3) than at most of the free stream stations (E1–E3). Importantly, the nearest growth index was correlated with the concentration of medium-sized particles (Fig. 8), these being the size fraction appropriate for pelagic juveniles of 70–15 mm SL. This assumes that the zooplankton conditions recorded by the OPC between 5 and 25 m depth were those experienced by the larva over the previous two days. In general, smaller myctophid species tend to persist in the 25–75 m depth range (Hopkins and Gartner 1992). Although higher recent growth was correlated with higher microzooplankton at the northern stations, the greatest abundance of microzooplankton found in the net was at Station N1, where very few larval were present. The higher biomass in the region of flow disturbance is probably due to convergence and aggregation rather than to enhanced production, because current flow had temporarily reversed during the previous week (discussed below).

Recent growth in pelagic juvenile cod off eastern Canada also exhibited higher correlation with the largest size fraction (>1050 µm) than with the smaller size fractions (Sutphen et al. 1989). Bailey (1989) also observed significant correlations between recent otolith growth and zooplankton biomass in pelagic juvenile walleye pollock.

Intercomparison of RNA and Otolith Growth Indices

The concentrations of RNA found in D. kapalae are much lower than those previously reported (e.g., Westerman and Hoit 1994). Although the present technique uses a different procedure and dye, freeze-drying is unlikely to have affected RNA yields, as many other studies also freeze-dry samples before analysis (e.g., Buckley and Lough 1987; Malloy and Tarpley 1994). Most other studies of RNA
Condition are conducted at temperatures much lower than those recorded here (25°C) and in larvae rather than pelagic juveniles. Malloy and Targett (1994) state that RNA measures of juvenile summer founder are much lower and less responsive to growth rate at temperatures 25°C, partly because of increased turnover rates of ribosomes and enzymes. Hence, the RNA concentrations in D. kapalae are probably consistent with slow-growing pelagic juveniles (0.1 mm day−1, Fig. 4; Gartner 1991a) in tropical oligotrophic waters with nutrients at or below detectable limits.

Biochemical and otolith analyses were conducted on pelagic juveniles from the same net tow but not on the same individuals. Consequently, any comparison between the two measures (Fig. 11) assumes that the two analyses reflect, on average, similar larvae from the same oceanographic conditions. The validity of this assumption probably declines with greater intervals before capture. The RNA-only weight index was positively correlated with the recent growth index over Days 1 and 2 and Days 3 and 4 before capture, but the correlation was not significant at Days 5 and 6. In general, RNA indices reflect conditions over the previous day (Martin and Wright 1987). An interesting exception was the very low RNA-DW index at Station E3 (Fig. 10), relative to the above-average otolith index at E3, particularly at Days 3 and 4 (Fig. 7). The fish at E3 appear to be in declining condition owing to temporal variation in the wake, and the otolith index may be less responsive than RNA concentrations.

Other studies that have examined otolith and RNA indices (Hovendenkamp 1990; Hovendenkamp and Wiss 1991; both also not of the same individuals) show that RNA and otolith condition are consistently correlated. Otolith and biochemical analyses of the same individuals are possible, e.g. Suther et al. (1992) and should be further examined.

Relationship of Condition to Current Flow

Axlema currents were deployed from October 1992 to February 1993 at two locations on Cato Reef along the 50-meter isobath (P. Coutts and J. H. Middleton, personal communication). Daily current records were predominately to the north at 30 cm s−1 during most of January 1993 and particularly during the 4-5 days before biological sampling. At 5-10 days before sampling, however, current exhibited some significant reversals to the south (possibly associated with Cyclone Oliver near Wreck Reef, 130 km north-north-east). The current meter data are consistent with the recent otolith growth index, which showed that by Days 5 and 6 before capture there was no significant difference between any of the stations.

The physical data enable interpretation of another apparent anomaly in the condition data. Otolith and RNA indices showed that condition at Station N2 was not significantly different from the overall average condition (Figs 7 and 10), with greater condition at N3. Modelled steady-current flow reveals an anticyclonic eddy north-west of Cato Reef, with a residence time of about two weeks (I. Coutts, personal communication), and this is apparent in the ADCP flow at 50 m (Fig. 1). Station N2 could have received an influx of poor-condition larvae from Station E1 that may have reduced the overall average.

Life-history Information of D. kapalae

The brown, white continuous zone of outer growth increments was formed in the surface waters during darkness between 1900 and 0400 hours, whereas the brown, white discontinuous zone appears to have formed during daylight, presumably at depth (Fig. 5). Thus, one complete increment is assumed to form every 24 h. Although individuals were sampled only over 8 out of 24 hours, this conclusion is identical to that of Gartner (1991a), who sampled three species of myctophids over the full 24 h. No pelagic juvenile myctophids were captured during the present daylight sampling, from the surface to 120 m.

The brown (metamorphic) zone of the otolith (Fig. 2) has been argued as representing a shift between the larval habitat (surface waters) and the sub-adult habitat (>200 m, Gjøstøler 1987; Gartner 1991a). Liokovics (1994) suggests that the formation of accessory primordia (APs) at the beginning of this zone does not necessarily correspond to metamorphosis, as APs were observed in, this zone before size at transformation (reported to occur around 11.5 mm SL). Similarly, in the present study APs were calculated to occur at about 10.8 mm SL. APs occur when the axis of growth shifts from being centred about the central primordium to being centred about the accessory primordia and is probably associated with a change in habitat and the development of invertebrate diet at this migration.

Incremental growth was observed to occur in the surface waters at night, supporting Gartner's (1991b) conclusion that myctophids are ecologically epipelagic rather than mesopelagic. The larval duration of D. kapalae is about 38 days, which is at the upper end of the range for nine myctophids reported to have larval durations of 26-40 days (Gjøstøler 1987; Gartner 1991b).

Biological Significance of Flow Disturbance about an Island

The effects of flow disturbance on pelagic juvenile condition are complex, including the shape and stability of the eddies downstream (e.g. Cowen and Castro 1994), current flow the previous week, possible mixing of starving and feeding individuals, possible trophic lag effects, and predation. The potentially confounding influence of island runoff is not possible around a small, low-relief island such as Cato. However, the spatial/temporal scales of observation


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