

**Marine Lake Monitoring Project Update, 2001:
Biological and Physical Properties of Goby Lake, Big Jellyfish
Lake, and Ongeim'l Tketau**

by

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Abstract:

The Coral Reef Research Foundation has been monitoring physical and biological parameters in Ongeim'l Tketau (OTM), Big Jellyfish Lake Koror (BJLK), and Goby Lake Koror (GLK) since December 1998. Since the beginning of 2001, CRRF has visited each lake at least once per month and recorded temperature, salinity and oxygen profiles, the abundance and size frequency distribution of the scyphozoan *Mastigias* sp., Secchi disc depth, and zooplankton abundance (OTM only). The Marine Lake Monitoring Project (MLMP) has also deployed two thermographs per lake that collect temperature data at 30-minute intervals.

The MLMP has documented the steady recovery of the OTM *Mastigias* sp. medusae population since their reappearance in December 1999. As of December 2001, the lake contained approximately 20 ± 1 million *Mastigias* sp. medusae. During 2001, the MLMP also discovered and documented two biologically significant dysoxic (low oxygen) events in OTM. Data indicate that similar dysoxic events also occurred in both BJLK and GLK. In OTM, these events apparently killed all the sessile organisms living at the affected depths including mussels, sponges, algae and jellyfish polyps. In turn, the loss of the jellyfish polyps temporarily reduced ephyrae production and, in all but one instance, medusae abundance. These events also shed light on the disappearance of the medusae during the 1997-98 El Niño/La Niña event, which was accompanied by a significant shallowing of the dysoxic/anoxic boundary (chemocline).

This report offers preliminary qualitative interpretations of data collected during 2001. It is not intended to be a robust nor final treatment of the subject. Please contact the authors for permission, corrections, and caveats before citing this work.

I. Introduction:

Since the unprecedented disappearance of *Mastigias* sp. medusae from Ongeim'i Tketau (OTM) in December 1998, CRRF has monitored physical and biological parameters of OTM as well as those of Big Jellyfish Lake Koror (BJLK) and Goby Lake Koror (GLK), two reference ecosystems that also contain large, perennial, populations of *Mastigias* sp. (Figure 1).



Figure 1. Study sites: Ongeim'i Tketau (OTM), Big Jellyfish Lake Koror (BJLK) and Goby Lake Koror (GLK).

Although the disappearance (and eventual recovery) of *Mastigias* sp. medusae in OTM coincided with obvious and dramatic changes in the salinity, oxygen and temperature profiles of the lake, initial efforts to understand the disappearance of the *Mastigias* sp. medusae were hindered by a lack of baseline data describing the average physical and biological conditions of the ecosystem (Dawson *et al.*, 2001). Additionally, we lacked a lake-specific understanding of the factors that stimulate (and thus, in their absence, limit) medusa production in these ecosystems. These four factors, the unprecedented disappearance, the physical perturbations that accompanied the disappearance, the lack of baseline data describing average physical and biological conditions in the lake, and a lack of information regarding the biology of medusa production, determined the goals of the Marine Lake Monitoring Project (MLMP) which are as follows. One, to document the recovery of and subsequently monitor the *Mastigias* sp. populations in OTM, BJLK, and GLK as well as coincident changes in the physical parameters of the lakes. Two, to collect baseline data describing basic physical and biological properties of these ecosystems and relate them to weather patterns. Three, to understand the factors that affect medusa production in the lake and, four, to provide these data and analyses to local agencies to facilitate sustainable management these unique resources.

II. Materials and Methods:

The MLMP has been collecting the following four types of data, on at least a monthly basis, in OTM, BJLK, and GLK over the last three years. First, physical profiles, detailing the temperature, salinity and oxygen concentrations at one-meter intervals from 0 to 24 m or the bottom, whichever is encountered first, are made at two sites per lake using a Hydrolab Quanta environmental meter. Second, medusae population size and size frequency distribution are estimated by sampling a set number of stations per lake. Medusae are caught using a 50 cm diameter, <1000 μ m mesh net hauled vertically from the chemocline to the surface. The diameter of each captured medusa is determined to the nearest 0.5 cm by laying the medusa, aboral side down, on a ruled slate. In OTM, the complete set of stations is sampled at least twice on a given day to produce an average number of medusae caught per set or “run”;

each run provides an independent estimate of medusae abundance. The average abundance of medusae per haul per run is used to estimate medusae population size. Third, primary productivity is approximated as Secchi disc depth determined at a minimum of two sites per lake. Fourth, zooplankton samples are collected at three sites using an 80 μm mesh net hauled vertically from the chemocline to the surface. Zooplankton abundance is estimated as the mean volume of the concentrated samples (OTM only).

The MLMP also has deployed two thermographs per lake at two different depths to record temperature at 30-minute intervals. Deployment depths are based on the spatial distribution of the benthic life stage of the scyphozoan life cycle (the polyp). Although not reported herein, these data will provide insight into the lakes' heat budgets with respect to both climatic variables and the heat budget of the surrounding lagoon. Additionally, they will allow us to explore the relationship between temperature and medusa population dynamics.

Finally, the MLMP conducted a macrophotographic study of the polyp stage during two periods in 2001, January to May and mid-August to September. The goals of this study were to investigate factors that influence strobilation at the level of the individual polyp and to ensure that net-based estimates of ephyrae abundance accurately captured strobilation events as documented in the polyp population. At this time, only preliminary analyses have been completed but they suggest a strong positive correlation between numbers of ephyrae caught in net tows (defined as medusae $\leq 0.5\text{cm}$ diameter) and numbers of polyps observed strobilating in photographs indicating that MLMP sampling methods are sufficient to capture strobilation events.

III. Results and Discussion:

Mastigias sp. Population Dynamics in 2001:

In OTM, end of the year *Mastigias sp.* medusae population sizes exceeded those in January by a factor of 8, increasing from approximately 2.2 million individuals in January 2001 to a high of approximately 19.8 million in December (Figure 2). In contrast, population sizes in both GLK and BJLK varied throughout the year but showed no consistent trends with time. Overall, the population dynamics of each lake appeared to be independent, behaving largely asynchronously through much of the year.

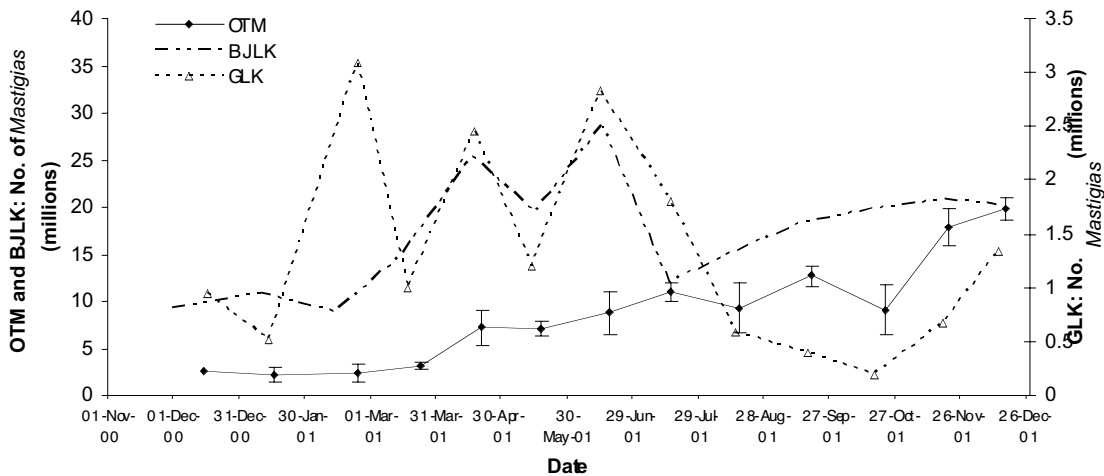
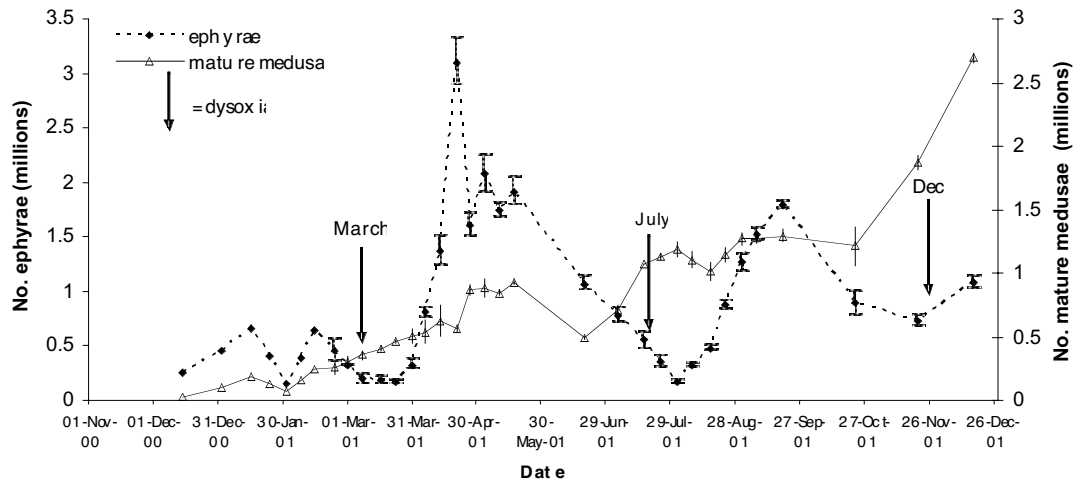


Figure 2. *Mastigias sp.* population size (millions) in OTM ($\pm 95\%$ CI), BJLK, and GLK.

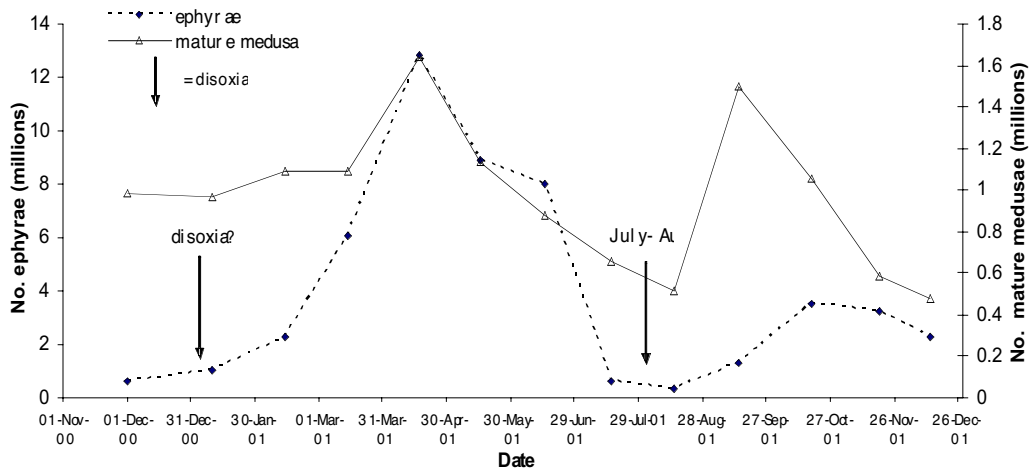
Since the reappearance of the medusa stage in OTM in December 1999, *Mastigias* sp. medusae populations have been maintained perennially in all three lakes by continuous strobilation (the production of ephyrae by the benthic polyp stage). 2001 was no exception; continuous background strobilation was interspersed periodically with larger strobilation events that, for the most part, occurred asynchronously among all three lakes (Figures 3a-c). Within each lake, however, changes in ephyrae abundance often appeared to track changes in the abundance of reproductively mature medusae. Exceptions to this pattern may be attributed to dysoxic events (periods of unusually low oxygen; see discussion of oxygen profiles), which temporarily reduced polyp abundance and/or inhibited strobilation by surviving polyps and thus, the numbers of ephyrae produced. With the exception of the dysoxic event in GLK during the July-August period (Figure 3c), ephyrae production in all three lakes increased substantially after each dysoxic episode abated. Notably, the absence of a large strobilation event following the July-August dysoxic event in GLK coincided with relatively low numbers of mature medusae.

These data suggest processes that may influence medusae abundance in the lakes. The visually apparent (but statistically untested) association between the number of mature medusae and ephyrae abundance suggest that these two life stages are linked in a feedback loop with a short time lag. According to this hypothesis, larvae produced by the mature portion of the medusa population rapidly progress through settlement and early developmental stages, strobilating as soon as they reach the appropriate size (16 tentacle stage). Thus, at any given time, ephyrae abundance is determined in large part by the supply of larvae, which, in turn, is governed by the number of extant mature animals.

a. OTM



b. BJLK



c. GLK

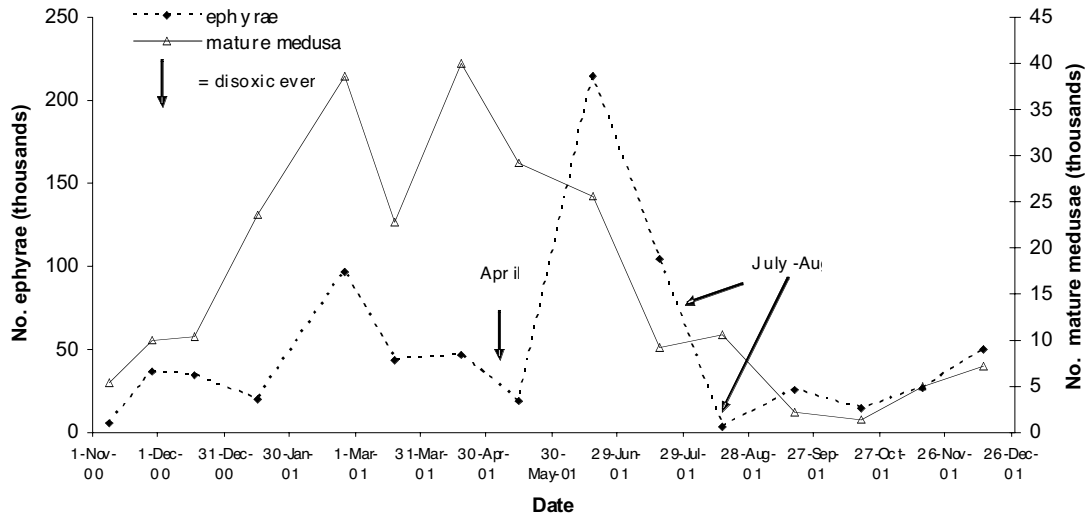


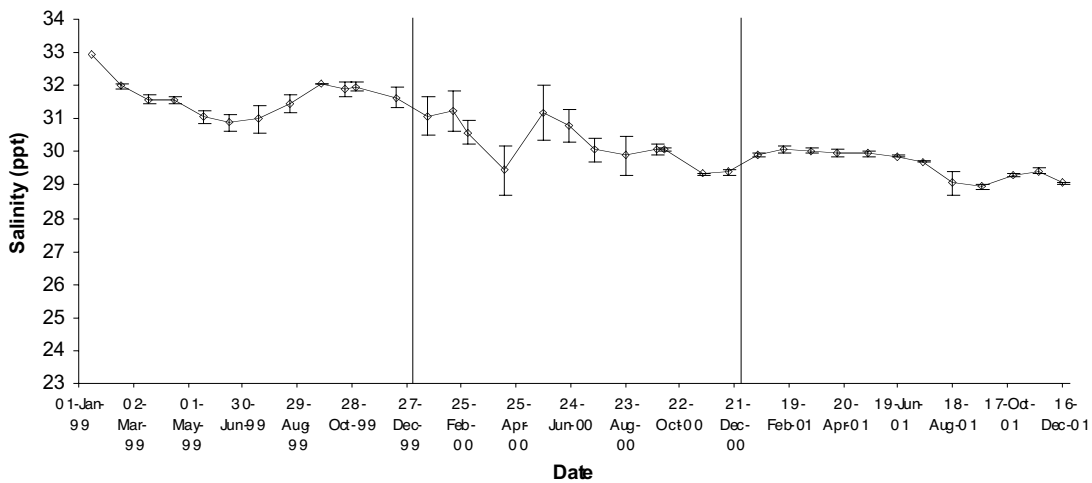
Figure 3. Abundance of *Mastigias* sp. ephyrae and mature adults (individuals ≥ 6.5 cm diameter) in OTM ($\pm 95\%$ CI), BJLK, and GLK. Vertical arrows indicate dysoxic events.

Such a tight feedback loop potentially explains several facets of medusae population dynamics in these lakes including aspects of the 1998 disappearance in OTM, the pattern of recovery in OTM, the explosive growth observed in OTM during 2001, and the observation that strobilation occurs continuously throughout the year in all three lakes apparently without any strong and readily predictable links to changes in environmental factors like temperature, oxygen or productivity. It seems likely that as long as events that kill or prevent polyps from strobilating, like the dysoxic events that occurred in 2001, do not coincide with a natural decline in the abundance of mature medusae (as they did in GLK during the second dysoxic event of 2001), medusae populations will remain robust.

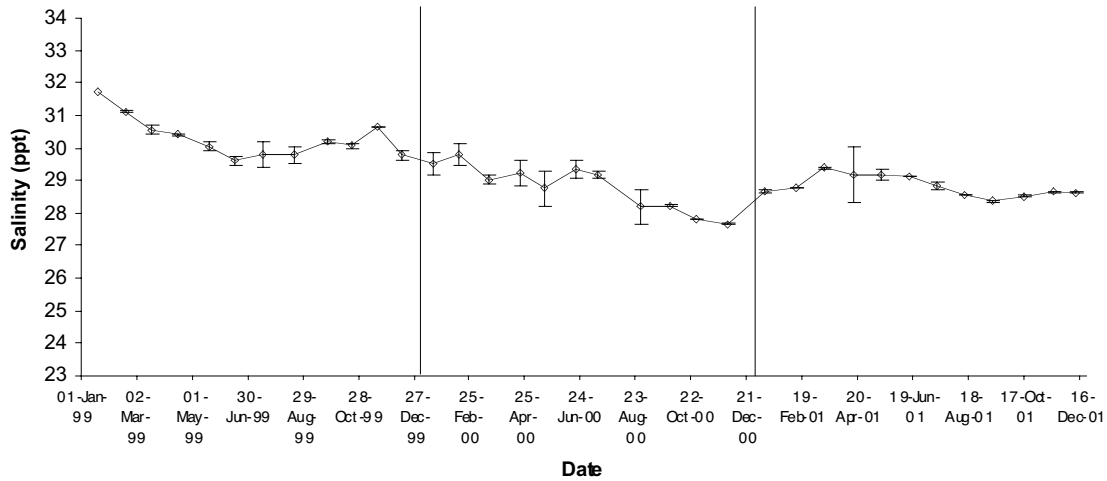
Salinity, Temperature and Oxygen Profiles December 1998 – November 2001:

In 2001, all three lakes continued to show similar temporal trends in average salinity for the depths at which polyps are found (Figures 4a-c), suggesting that salinity is regulated by factors that affect all three lakes similarly and simultaneously (e.g. weather). During the first half of 2001, salinity increased by approximately 1-1.5 ppt, subsequently decreasing to the year’s low in September before beginning to rise again through November.

a. OTM



b. BJLK



c. GLK

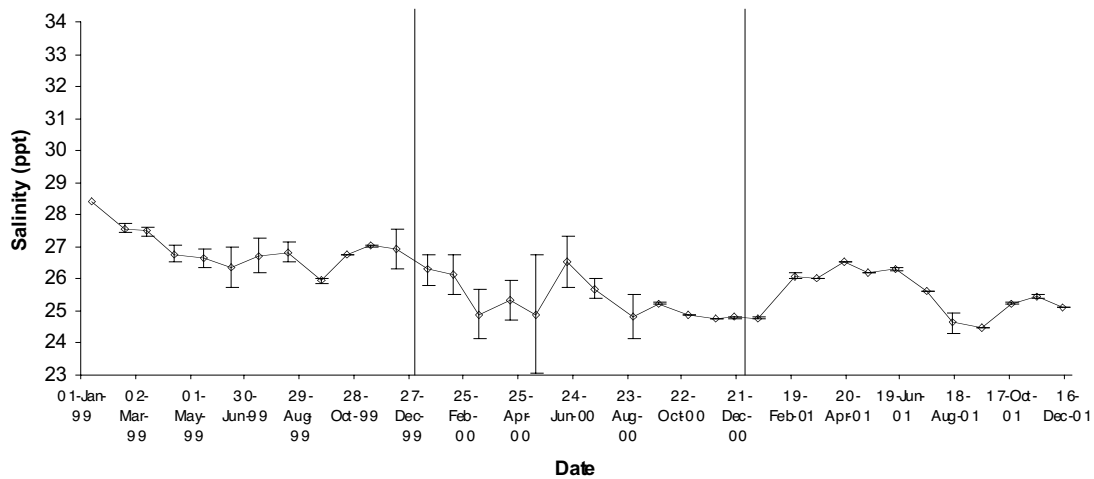
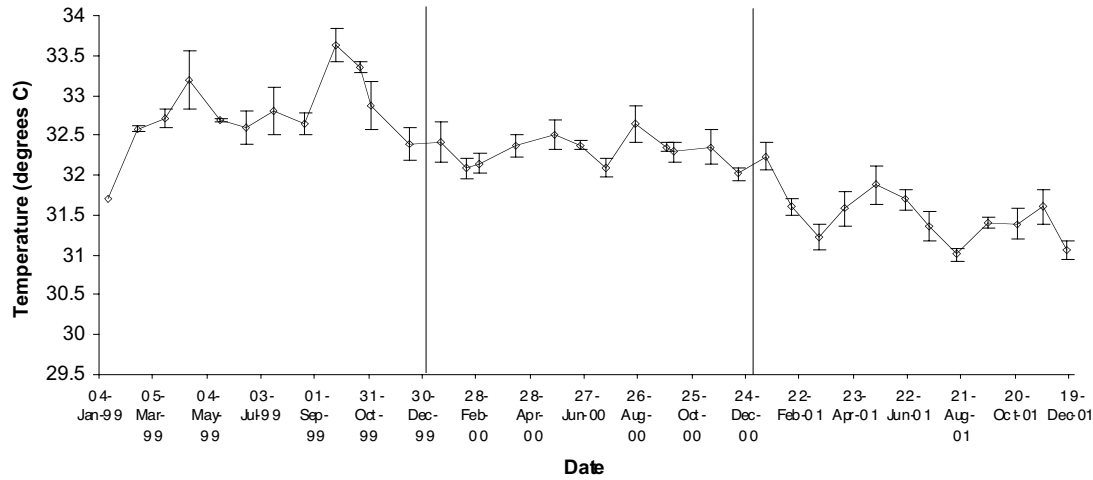


Figure 4. Trends in average salinity (\pm 95% CI) across the depths at which polyps occur in OTM (6-12m), BJLK (6-14m), and GLK (3-6m) between November 1998 and December 2001. Note the differences in scales.

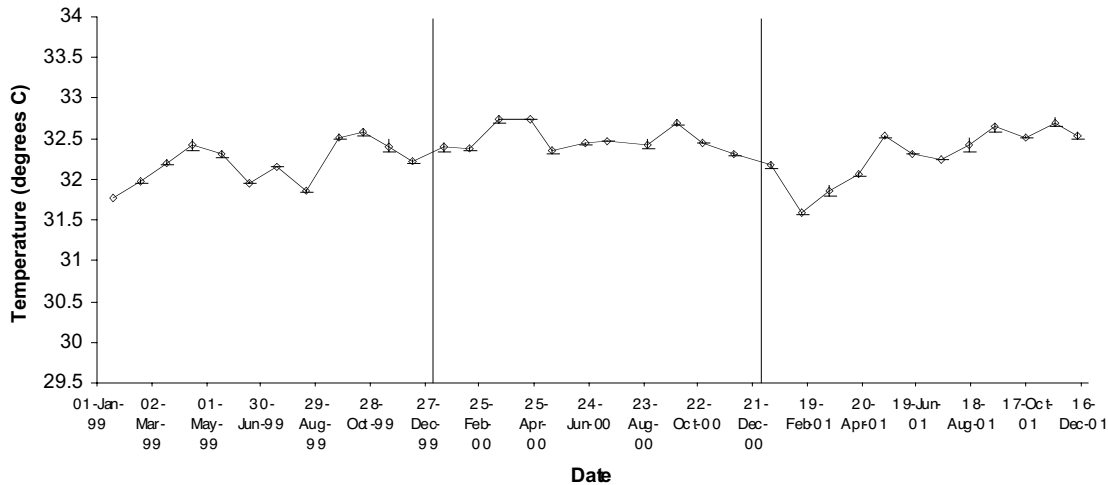
Average temperature trends at polyp depth were superficially similar but varied in both the timing and duration of highs and lows among the three lakes (Fig. 5a-c). Each lake experienced temperature declines at the start of 2001 and subsequent warming but the degree and pattern of changes varied between lakes. For example, overall, OTM cooled, BJLK and GLK warmed, and all fluctuated during 2001.

In general, GLK exhibited the greatest variability in average temperature at polyp depths, varying 2.1 °C over the course of the year while in OTM and BJLK the greatest differences were 1.2 and 1.1 °C, respectively. GLK also continued to exhibit the most dynamic temperature regime, with relatively large temperature changes occurring over the course of single months rather than more gradually as observed in both OTM and BJLK. These inter-lake differences in trends suggest that, in contrast to salinity, heat budgets are determined largely by lake-specific processes.

a. OTM



b. BJK



c. GLK

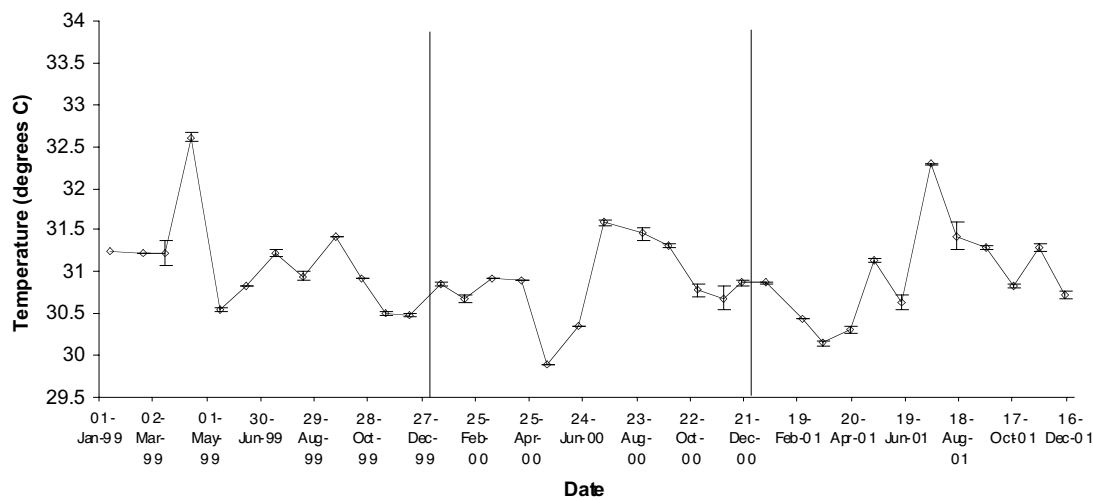


Figure 5. Trends in average temperature (\pm 95% CI) across the depths at which polyps occur in OTM (6-12m), BJK (6-14m), and GLK (3-6m) between November 1998 and December 2001. Note the differences in scales.

Trends in average oxygen at polyp depth in all three lakes were similar but with a substantial amount of inter-lake variation. In all three lakes, the highest oxygen concentrations were observed during the first quarter of the year, declined subsequently, and never returned to the initial high levels (Fig. 6a-c). The decline was most dramatic in OTM, which steadily decreased from a high of

approximately 4.5 mg L^{-1} in January to fairly stable but persistently low readings of less than 1.5 mg L^{-1} by May. Oxygen concentrations in BJLK generally declined over the course of the year. Again, GLK behaved most dynamically, showing large changes in oxygen concentrations over relatively short time scales.

All three lakes experienced dysoxic events during the July-August period. During these events, oxygen concentrations below 8m in OTM, 12m in BJLK, and 5m in GLK, dropped to levels that would induce hypoxia (low-oxygen related stress) in many marine animals. In all three lakes, these events coincided with the shallowest Secchi disc depths (indicating the highest levels of primary productivity) measured during the year (Fig.7 a-c) and occurred just after Tropical Storm Utor inundated Palau with rain.

Our preliminary interpretation of these temporal relationships is that nutrient enriched storm runoff from the surrounding jungle stimulated the development of large phytoplankton blooms (and subsequently micro-zooplankton blooms) which, as they died back, fueled the development of large decomposer populations. Decomposer respiration rates subsequently exceeded the rate at which new oxygen was introduced to these depths and oxygen levels declined accordingly. This situation may have been exacerbated by accumulation of large amounts of rainwater at the surface of the lake, which, by strongly stratifying the lake would have reduced mixing and limited the introduction of oxygen from the surface into deeper waters.

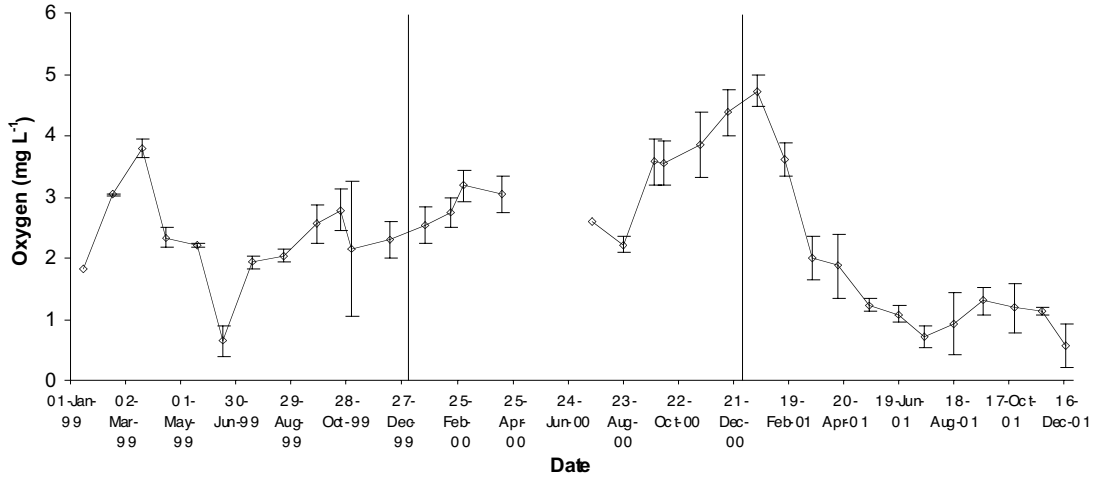
We also documented two additional dysoxic events in OTM, one during March-April and a second in November-December. While the decline in mean oxygen concentration at polyp depth during the December event is obvious, that of March-April appears comparatively unremarkable (Figure 6a). This discrepancy is due to differences in the depth to which low oxygen levels penetrated. During the March event, the water column was very well oxygenated to a depth of 8-9m before abruptly declining to dysoxic conditions at 10 m. In contrast, during the December event, very low oxygen concentrations began at 6 m. As during the July-August dysoxic event, both the March-April and November-December events coincided with phytoplankton blooms, as indicated by reduced Secchi disc depth.

BJLK and GLK also experienced additional dysoxic events during 2001. BJLK experienced a second event during December 2001, which coincided with that in OTM. Secchi and oxygen data indicate that GLK also experienced a dysoxic event during April.

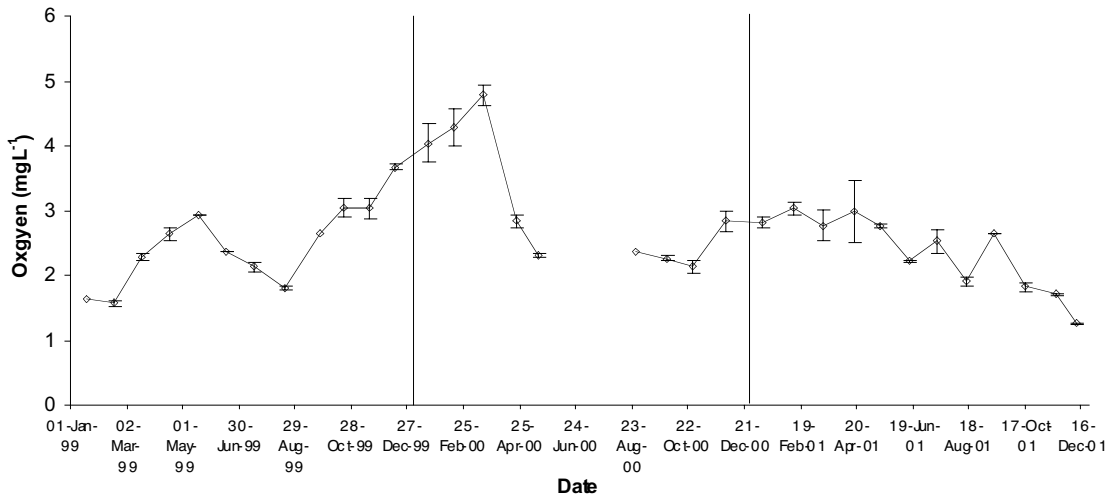
These dysoxic events had important consequences for the organisms that inhabited the affected depths. In OTM, weekly SCUBA dives revealed widespread mortality of the normally abundant sessile organisms trapped in these zones including sponges, mussels, algae and large numbers of jellyfish polyps. Although no diving was done in GLK, water drawn from 7m during the July-August event smelled strongly of hydrogen sulfide indicating that, atypically, this water had become anoxic at that depth and lethal to aerobic organisms including jellyfish polyps. Additionally, in all three lakes, dysoxic events typically were followed by a temporary decline in ephyrae production and reduced abundance of medusae.

A review of the oxygen data collected since 1998 suggests that dysoxic events probably also occurred in 1999 and 2000. However, at that time, they went unrecognized because the MLMP did not regularly involve diving in OTM and, thus, was unable to correlate changes in oxygen profiles with ecological changes in the benthos. Data from December 1998 also indicate that a dysoxic event likely contributed to the loss of medusae from OTM during the 1997-98 El Niño/La Niña since their disappearance was accompanied by a pronounced shoaling of the dysoxic/anoxic boundary (Dawson *et al.*, 2001). Thus, the cumulative evidence indicates that these types of low oxygen events likely play an important role in the medusae population dynamics of these systems.

a. OTM



b. BJLK



c. GLK

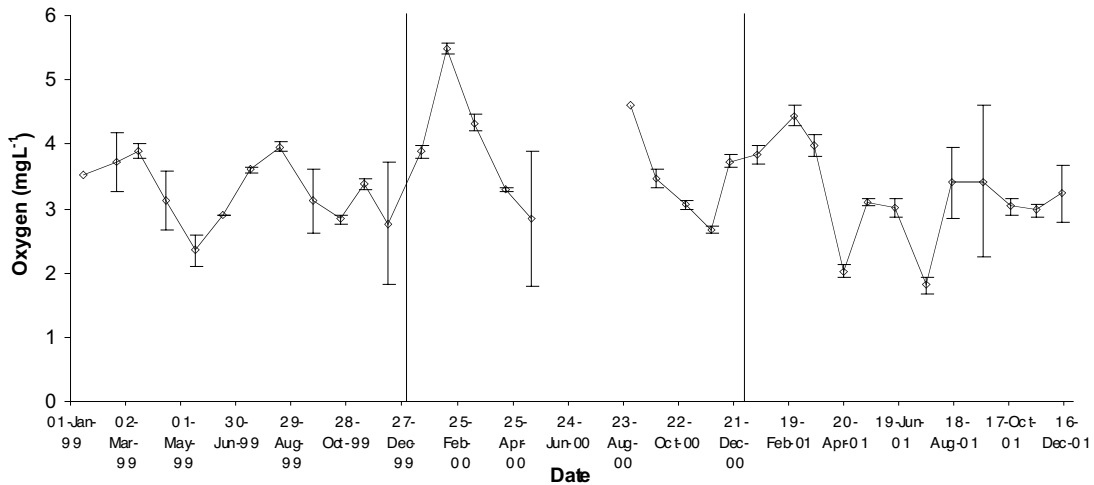


Figure 6. Trends in average oxygen (\pm 95% CI) across the depths at which polyps occur in OTM (6-12m), BJLK (6-14m), and GLK (3-6m) between November 1998 and December 2001.

Future work:

The MLMP will continue to monitor all three lakes through 2002. We will, however, expand our monitoring efforts to include the regular collection of zooplankton samples from BJLK and GLK. We also plan to estimate the accuracy and precision of *Mastigias* sp. population sizes in both BJLK and

GLK by measuring medusae abundance twice per sampling day, rather than once per day as we did during 2001. Finally, the MLMP will begin to collect data describing changes in oxidation-reduction potential with depth. These data will improve our ability to detect changes in the depth of the chemocline and to determine the differences between dysoxic conditions, which may be tolerated by aerobic organisms, and anoxic conditions, which are lethal, thus providing greater insight into the factors affecting medusae population dynamics in these ecosystems.

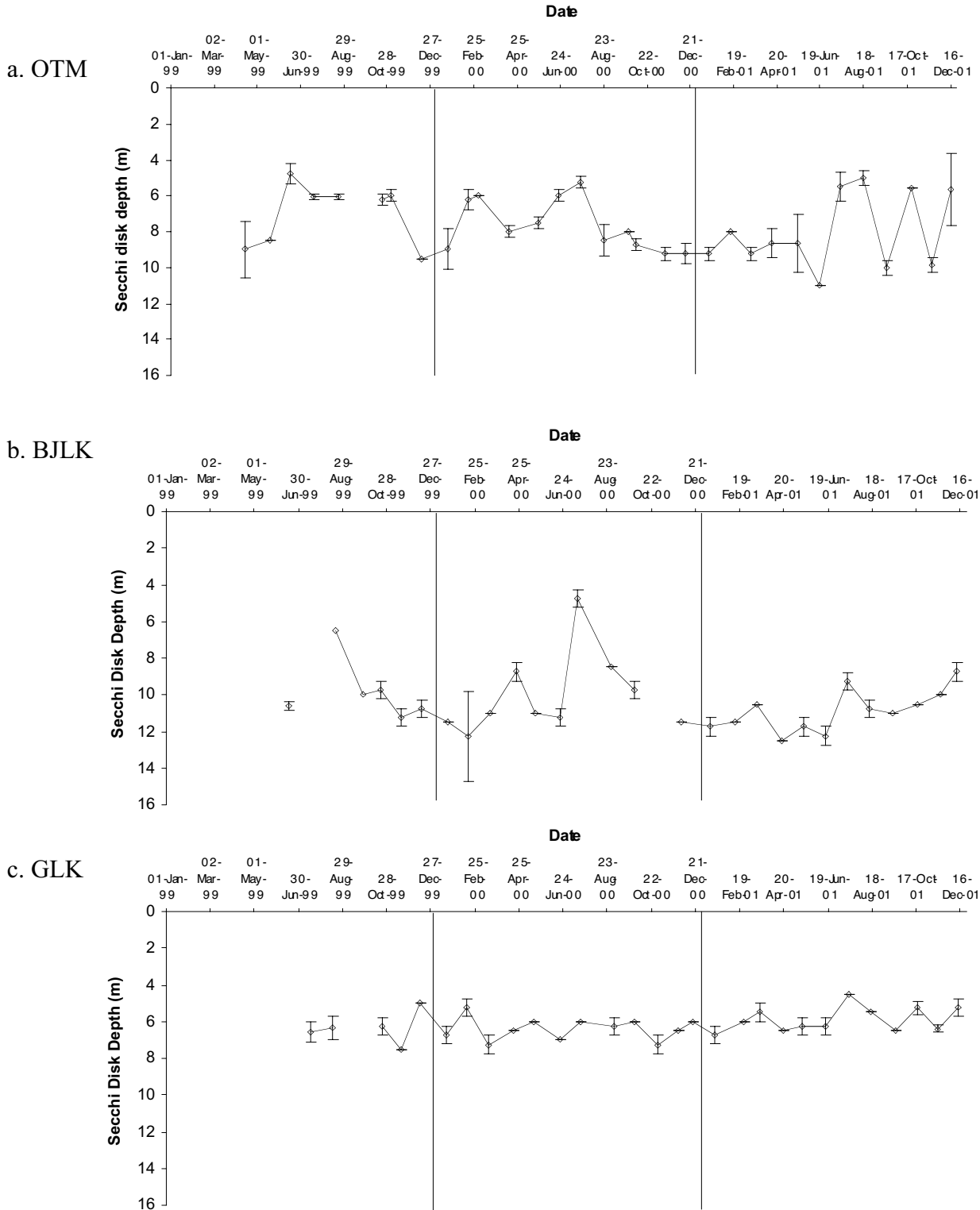


Figure 7. Trends in average Secchi disc depth (\pm 95% CI) in OTM, BJLK, and GLK from 1999 to December 2001. Note different scales. Data collected at monthly intervals.

Literature Cited

Dawson, M.N, Martin, L.E., and L.K. Penland. 2001. Jellyfish swarms, tourists, and the Christ Child. *Hydrobiologia*. 451:131-144.