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Title: Investigation of Possible Daily Coastal Upwelling Effect on two Different Relief Areas: High Relief Half-Graben Faults and Low Relief Coastal Plains in Lake Tanganyika, East Africa.

Introduction

Water movements influence the distribution of nutrients, microorganisms, and plankton in the mixolimnion of Lake Tanganyika. Catabatic and offshore winds may have a profound effect on these water movement patterns. Radiation by the sun and evaporation are other important contributing abiotic forces that influence water movements in the lake. A daily pattern of offshore winds in the morning and onshore winds in the evening generated by the difference in air temperature between the lake and the rifts surrounding it may give rise to a measurable upwelling effect in the early morning when the epilimnion is isothermal. Due to the strong temperature difference between the surface water and the high relief rift mountain surrounding much of Lake Tanganyika, the effects of the wind are likely to be stronger along the coast boarded by mountains compared with the lower relief, plain regions (mountain wind effect).

Along the Tanzanian coast of lake Tanganyika, temperature patterns suggesting strong upwelling currents from the metalimnion have been observed (from satellite imagery), which might be due to the combined effects of offshore winds and catabatic winds.

A horizontal and deep vertical sampling regime was performed to examine the thermocline and lower mixolimnion and to measure this effect of the wind on abiotic parameters of the water column in two different relief areas near Kigoma (i.e. highlands and low lands). The first sampling station was in Kigoma Bay, an area of low relief where the half-graben rift tips out into Lake Tanganyika. The basin is relatively shallow and flat until a depth of approximately 150 meters, then drops off quickly. The second sampling station was just north of Gombe National Park, near the outflow of the Mwamgongo River, which is bordered by high rift mountains. The basin drops off quickly near the shore and reaches depths of over a kilometer within a few kilometers offshore.

Objective of the study

The objective of the study was to measure the effect of daily coastal upwellings (at 0600 hrs and 1700 hrs) during the dry season on Lake Tanganyika. Previous data indicate that at 0600 hrs the epilimnion is cooling at night to the thermocline;

this convective mixing of the epilimnion may be due to the advection mixing (upwelling) as the water is pushed by the catabatic and offshore winds in the early morning.

Material and Methods

Materials

- YSI D.O./Temp meter
- Secchi Disk
- 6 Thermistors and chain water sampler 2L.
- Weather Monitor II weather station Wind
- Anemometer
- pH meter
- HACH Co. DR/2010 Spectrophotometer
- Conductivity meter
- HACH Co. reagents for nutrient analysis
- Turbidimeter

Sampling Site Location

The location of sampling sites was chosen based on the measured depth of the thermocline. Three sites at each station were chosen; Site 3 was located offshore at the depth of thermocline, Site 2 was located at approximately half the depth of the thermocline, and Site 1 was located close to shore. At both of the two sampling stations (Kigoma Bay and Mwamgongo area), Site 3 was located at a point of more than 60 meter depth (65-80m) so as to make sure that sampling to the metalimnion waters was possible. Site 1 of each sampling station was located at >20m from the shore where the depth of the lake was approximately 10 meters for Kigoma Bay (low relief) and 20 meters for Mwamgongo (high relief). Site 2 of each sampling station was in between site number one and three, located where the depth of the lake was about 40m. The position of each sampling site was recorded with a GPS (Table 1). Due to the difference in basin morphometry, distances between stations were much larger in Kigoma Bay than at Mwamgongo.

Table no. 1: Coordinates of sampling sites.

| Location | Sampling sites | Latitude (S) | Longitude (E) |
|------------|----------------|--------------|---------------|
| Kigoma Bay | Site 1 | 04° | |
| | Site 2 | 04° | |
| | Site 3 | 04° | |
| Mwamgongo | Site 1,2 and 3 | 04° | |
| | | | |
| | | | |

Sampling Types

Two replicate morning and two replicate evening samples were obtained at each station. A regular sampling of one-day alternation between morning (at 0600hrs) and evening (at 1700hrs) was performed at Kigoma Bay for a period of four days. At Mwangongo, there were intensive sampling of two times daily (at 7:30hrs in the morning and 1700hrs in the evening), for the period of two days.

Sampling Methodology and Instrumentation

A long term, continuous temperature depth profile at each site was obtained by placing the thermistor chain in the water to record temperature after every 10 min for the sampling period. At Kigoma Bay, thermistors were placed at 05 m, 15 m, 30 m, 45 m and 60 m depth. At Mwangongo, thermistors were placed at 05 m, 30 m, 60 m and 80 m depth.

Water samples of 2.0 liters capacity were collected at 60m, 30m, and 5m for each sampling Site 3 at Kigoma Bay and 80m, 30m, and 05m at Mwangongo. At Site 2, samples were collected at 30m, and 5m for each sampling station. At Site 1, samples were collected at 5m for Kigoma Bay and 5m and 20m for Mwangongo. Water samples were measured for pH and conductivity (C) in the field, and turbidity (Turb), silicate (SiO_2), phosphate ($\text{PO}_4\text{-P}$ or SRP) or total phosphorus (TP), nitrate (NO_3), nitrite (NO_2), and ammonia (NH_4) in the lab.

At each of the three sites, vertical profiles of DO and T were taken every 10 meters from the surface to the bottom and transparency was measured with a 20cm diameter secchi disk. *In situ* D.O. and T measurements could not be taken greater than 60m in depth due to the length of the cable attached to the probe.

Table 2: Parameters measured by spectrophotometer (HACH DR/2010), methods and corresponding precision and units (United States Environmental Protection Agency approved)

| Parameters | Methods | Preci- sion and units |
|--|--------------------|--|
| Ammonia mg/L ($\text{NH}_3\text{-N}$) | Nessler | +/- 0.01 |
| Nitrate mg/L ($\text{NO}_3\text{-N}$) | Cadmium reduction | +/- 0.01 |
| Nitrite mg/L ($\text{NO}_2\text{-N}$) | Diazotization | +/- 0.001 |
| Total Phosphorus mg/L ($\text{PO}_4\text{---}$) | Acid persulfate | +/- 0.01 |
| Soluble Reactive Phosphates bic Acid | Ascor- bic Acid | +/- 0.01 mg/L ($\text{PO}_4\text{-P}$) |

Results-Mwansa, P.K.

Wind direction and speed

As Plisnier et al. (1996) states, the best place to start to describe the limnological cycle of Lake Tanganyika is the wind, which regulates the energy input into the Lake through physical processes and causes mixing. During the study period, wind direction changed greatly. The prevailing winds were generally easterly winds during the night (19:00-0600hrs) and morning (7:00-11:00) and northwesterly wind in the afternoon (12:00-18:00). According to Coche (1968), better mixing due to greater turbulence within the coastal water mass exists if the shore lies perpendicular to the main wind.

Wind speed varied considerably during this period being strongest in the afternoons and low in the mornings. The average wind speed for Kigoma ranged between 1.28 and 2.15 m/second during the day and 0.28 to 0.54 during the night.

Air Temperature

Air temperatures at Kigoma Bay and Mwamgongo area were higher during the day and low during the night. Average daily temperature ranged from 27.7°C to 25.4°C and 18.53°C to 38.37°C for Kigoma Bay and Mwamgongo area respectively. The latter had the highest range of temperature about 19.84°C during the two day sampling period.

Water Temperature

Water temperature data was obtained from the thermistor chains that were anchored at each sampling station as well as from our in situ digital thermometer coupled to an oxygen meter.

From the thermistor chain results (Appendix G), water temperature was high during the day and lower in the night during the study period. On a daily cycle, mixing was observed particularly in the early morning (2:00a.m. and 9:00a.m.) when high winds coincided (Fig. 1 and 2). Besides this, water temperature was high in the top 40meter and decreased to 6 meter at each sampling occasion for both sites. Near-shore sites for both Kigoma and Mwamgongo were always warmer than the mid-shore and far-shore areas (Fig. 3, a;b;c).

The thermocline depth was very distinct only at far shore areas for both sites. The thermocline depth was constant, at 50 meters during all the sampling occasions.

Transparency

Water transparency was reasonably high throughout the study period. The highest secchi disk reading of 19.6 meters was obtained at Mwamgongo area both in the morning and afternoon. Generally, transparency of water masses at

Kigoma was lower compared to that of Mwamgongo area ranging from 10.6-13.2 meters and 12.2-19.6meters respectively.

Mwamgongo secchi disk readings were slightly higher in the morning than afternoon. In addition, far-shore readings were generally higher than the mid-shore and near-shore readings (Table 1). No clear cycle in water transparency was evident at Kigoma Bay site.

Results- Bungala, S.O.

Vertical profiles in the pelagic area

The general vertical profiles for chemical parameter are shown in the Appendix C. Thermocline depth was deep in highland areas, below 60m depth compared to lowlands, between 50 and 60m depth, probable due to high wind speed and intensity as wind speed data, dissolved oxygen data, and temperature data agrees.

Chemical parameters decreased with depth in the water except for conductivity, which tended to increase. This was probably due to an increase in the concentration of nutrients. Turbidity data was anomalous, 18NTU at 60 m depth, though probably due to sediments which were re-suspended in the water column when sampling.

Horizontal comparison

Variation of parameters detected in the pelagic area was also detected in coastal areas. (See appendix B) Generally mean values of chemical parameters (D.O, pH, Cond, and Turb.) were more varied in the pelagic areas compared to coastal areas.

Results – Hoffman, J.C.

Values of nitrates and phosphates were quite low at both stations during the entire sampling period (Appendix A); similar to long term data results from the Kigoma Bay area (Plisnier et al. 1996). Ammonium was problematic in field measurement. Silicate concentrations demonstrated a wide variation at both stations, from very low to unusually high concentrations. Generally, the ambient lake-water concentrations of the phosphates demonstrated less variability than the nitrate concentrations, suggesting that the system might be nitrogen limited and undergoes larger daily fluctuations.

Nitrate (NO₃)

Nitrate at both sites was highly variable and failed to show a distinct upwelling pattern, with elevated nutrient concentrations in the early morning (Appendices D and E). Concentrations ranged from 0.090 to 0.00 mg/L at Kigoma Bay and from 0.04 mg/L to 0.00 mg/L at Mwamgongo (Appendix A). Kigoma Bay generally had higher average concentrations of nitrate

present (Appendix A). At Kigoma Bay, nitrate tended to increase with depth and decrease over the sampling period (Appendix D). Concentrations at all depths varied widely. At Mwangongo, nitrate did not increase with depth and remained present at similar concentrations over the sampling period (Appendix E). Any comparison over time, however, is tentative due to the shortened sampling period at Mwangongo. Concentrations were less variable in the deeper waters.

Nitrite (NO₂)

Nitrite was also variable, however always present in the water column at both sites. At both stations, there was good evidence for daily upwelling, with values elevated in the morning over the previous afternoon (Appendices D and E). At Kigoma Bay, values ranged from 0.001 mg/L to 0.008 mg/L and at Mwangongo from 0.003 mg/L to 0.014 mg/L (Appendix A). Average values were higher at Mwangongo than at Kigoma Bay (Appendix A). At Kigoma Bay, concentrations varied at all depths, however Mwangongo again illustrated less variation at the deepest sampling site ($z = 60\text{m}$).

Ammonium (NH₄)

Distilled H₂O used for blanks to calibrate the spectrophotometer often had values of ammonia higher than the ambient lake-water concentrations. Most tests indicate some degree of contamination. Thus, while data recorded can be found in Appendix A, we feel that the poor data quality prevents any conclusive results.

Total phosphorus and orthophosphates (PO₄)

Phosphates were more stable in the water column than the nitrates and demonstrated less variability (Appendices D and E). Averages at Kigoma were slightly higher than at Mwangongo, with values ranging from 0.88 mg/L to 0.24 mg/L (Appendix A). Values at Mwangongo ranged from 0.004 mg/L to 5.00 mg/L. Contamination is suspected for the higher values at Mwangongo; any values over 0.40 mg/L are probably inaccurate based on the data from the other sampling times. At both sites, phosphates decreased with depth and were less variable in the deeper waters (Appendices D and E). There was little evidence at either station for a pattern of morning upwelling.

Silicate (SiO₂)

Silicates showed a strong increase with depth at Mwangongo, generally only trace values were found at 5 m depth while over 60 mg/L was found at depths of 60 m (Appendix E). Results from 28 June 1998 morning sampling are highly elevated and may indicate contamination, however the depth gradient is present throughout all sampling periods. An opposite effect was found in Kigoma Bay, with concentrations decreasing with depths (Appendix D). Overall, measured

concentrations were much higher at Mwangongo, ranging from 0.0384 mg/L to 63.45 mg/L. Concentrations ranged from 0.883 mg/L to 12.275 mg/L at Kigoma Bay (Appendix A). At Kigoma Bay, silicates tended to increase in the afternoon periods and become less variable in concentration with depth. Variation also tended to decrease with distance from the shore. Concentrations from the surface waters failed to provide evidence for an upwelling pattern. Data from Mwangongo also fails to illustrate an obvious morning upwelling effect, though values were highly elevated the first morning at depths greater than 20 m. Data from the second morning failed to corroborate this pattern.

Discussion and Conclusions

Daily Wind Patterns

There were significant fluctuations in daily average air temperature and wind speed. Generally, air temperature showed a similar trend with wind speed, with 9 moderate correlation coefficient of 55.2%. From the multiple correlation coefficient table (Appendix F), it is clear that air temperature and wind speed have an influence on the physical processes of the water masses especially up to the top 30 meters. The significance of these two factors becomes minimal downwards to 60 meters depth. Table 2 illustrates the multiple correlation coefficient between meteorological factors and the water temperature.

For both sites mixing (upwelling) of water occurs in the early hours of the day, showing no significant variation in terms of their different relief.

The transparency readings obtained during the study period varies considerably, may be due to turbulence mixing. This turbulence mixing may have been responsible for a high level of heterogeneity not only in transparency but probably, nutrients as well.

Analysis of the meteorological data has led to the following four conclusions. First, the wind speed at both Kigoma Bay and Mwangongo were usually lower than the air temperature and thus no significant mixing of nutrient rich deeper water with the surface water masses. Second, upwelling occurred in the early hours of the morning (00:00 to 7:00) each day of the study period in both Kigoma Bay and Mwangongo. Third, vertical fluctuations of water temperature were very significant during the study period. Fourth, future studies should try to quantitatively analyze the day and night variations in the lake resulting from meteorological factors.

Daily coastal upwelling effects

Winds cause the accumulation of warmer epilimnion water and thereby deepen the thermocline. When the forces of the winds weaken or cease, oscillations of the metalimnion forms

internal waves which were mainly detected below the thermocline.

Upwelling effects reached its maximum in the evening (after the wind had reached its maximum at noon), when the effects of the winds (internal waves and water circulation), maximize. This was agreed by the data of chemical parameters, wind speed and thermistor chain data. Chemical parameters (D.O., pH, and conductivity) were generally high in the evening compared to the morning; for example, D.O. was more than 100% saturation in the evening.

The thermocline was deeper at Mwangongo, the high relief area, compared to Kigoma Bay, the low relief area, temperature and D.O. data shows that.

Nutrient Dynamics

Nutrient data suggests four major conclusions in the data set. First, nitrate concentrations in the water column can vary widely over short periods of time. Stability in the upper metalimnion may prevent any major flux of nitrate to the surface waters, such that the wide variation may be a result of biological demand and nitrification in the mixolimnion.

Second, phosphorus concentrations in the water column remained relatively stable in the water column, suggesting both low biological demand and little contribution from the metalimnion. Based on both temperature and phosphorus data, it is unlikely that any morning upwelling actually entrains nutrients out of the metalimnion, though they may be entrained out of the lower epilimnion as the entire epilimnion cools.

Third, nitrite may be a good, measurable indicator of morning upwelling. Values were often higher in the morning hours, and because the nutrient must undergo further nitrification to be used by alga, it may remain long enough in the water column to be measured in the morning hours.

Finally, system dynamics and nutrient data appear to be closely correlated. Kigoma Bay generally showed more mixing in the upper layers and wider variability in the nutrient samples. The constant mixing in the upper layers may increase the patchiness. Further research between the relation of daily mixing brought on by the wind patterns (catatic and onshore and offshore winds) and nutrient availability may yield valuable information regarding physical controls on nutrient availability in Lake Tanganyika.

References

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