# Energy Transfer in Bang-tabun Bay from the Primary Producers to Primary Consumers

Monissa Srisomwong[1], Shettapong Meksumpun[1, 2*], Tada Kuninao[3] and Charumas Meksumpun[4]

## ABSTRACT

Energy transfer between trophic levels in Bang-tabun Bay was investigated during September 2012. Transfer was considered in terms of the carbon content in primary producers (phytoplankton) and primary consumers (zooplankton: copepods). Carbon content in phytoplankton varied between 563.22 and 3,492.70 $\mu g \cdot L^{-1}$ due to the abundance of nano- and pico-phytoplankton as the main source of carbon (62.8-92.0%). Carbon in copepods ranged between 21.97 and 278.51 $\mu g \cdot L^{-1}$. Energy transfer or trophic transfer efficiency ranged from 1.5% to 33.1%. Linear regression analysis showed a significant relationship between chlorophyll *a* and carbon content in phytoplankton at a significance level of 0.05 ($F=41.332$, $p=0.000203$). A linear correlation indicated $\widehat{C_i} = 139.416 \text{ Chl } a_i$ with $R^2$ of 81.8%, and this was used to estimate carbon content in phytoplankton when chlorophyll *a* concentration was known as a useful tool for energy transfer determination in aquatic environments.

**Keywords:** Bang-tabun Bay, Chlorophyll *a*, Phytoplankton, trophic transfer efficiency, Zooplankton

## INTRODUCTION

Community structure in aquatic ecosystems is composed of primary producers, primary consumers, secondary consumers, and detritus which comprise a food chain that links together to form a food web. Energy from the sun is absorbed by photosynthetic organisms and passes from one to another in the form of food. Only 5% to 20% of the biomass of primary producers is converted into new consumer biomass (Linderman, 1942), with the remainder lost during transfer or broken down in respiration. Energy transfer or trophic transfer efficiency (TTE) can be measured through trophic production, biomass size distribution, carbon flow, and radioactive flow (Gaedke *et al*., 1996; Schulz *et al*., 2004; Rousseau *et al*., 2000; Sanzone *et al*., 2003). Differences in TTE depend on several factors including number of trophic levels, efficiency of each level, feeding nature, food quality and quantity (Linderman, 1942).

Practicable energy transfer of organic carbon for single or multispecies fisheries can be used to maximize fish yields for sustainable management. Marine fish output can be estimated when primary production and number of trophic levels are known (Schulz *et al*., 2004) since transfer efficiency between trophic levels is usually around 10% (Pauly and Christensen, 1995). By contrast, study of energy transfer in Thai waters has limitations since it cannot be measured directly *in situ* and requires comprehensive knowledge (Gaedke and Straile, 1994). The present study examined the energy transfer or TTE from primary to secondary producers. Here, TTE in Bang-tabun Bay was

[1] Department of Marine Science, Faculty of Fisheries, Kasetsart University, Ladyao, Chatuchak, Bangkok 10900, Thailand.
[2] Center for Advanced Studies in Tropical Natural Resources, National Research University-Kasetsart University, Kasetsart University, Ladyao, Chatuchak, Bangkok 10900, Thailand (CASTNAR, NRU-KU, Thailand)
[3] Faculty of Agriculture, Kagawa University, Kagawa 761-0795, Japan
[4] Department of Fishery Biology, Faculty of Fisheries, Kasetsart University, Ladyao, Chatuchak, Bangkok 10900, Thailand.
* Corresponding author. E-mail address: ffisspm@ku.ac.th
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estimated in terms of the carbon content in each trophic level as carbon is considered to be a good measure of energy transfer through the food web (Gosselain *et al*., 2000; Saikia and Nandi, 2010). A regression equation of chlorophyll *a* and carbon content in phytoplankton was generated and used in carbon content estimation when data of chlorophyll *a* were accessible. Information regarding energy transfer mechanisms and interactions in aquatic ecosystems will improve understanding of functions in the fishery context, and thereby support managers to achieve optimal utilization of fishery resources.

## MATERIALS AND METHODS

### Study area

Bang-tabun Bay in Phetchaburi Province is located in the innermost region of the inner Gulf of Thailand. Freshwater runoff is loaded into the bay by the Bang-tabun River and the area is utilized as a fishing ground and for shellfish aquaculture. Cultured species include blood clams, oysters, green mussels, and hard clams. Nine sampling stations were selected to study the energy transfer between trophic levels during September 2012 (Figure 1).

### Phytoplankton sampling and analysis

At each station, 5 L of surface water was collected and placed in polyethylene bags. The water samples were stored in a dark and cold environment immediately after collection. For chlorophyll *a*, an aliquot of 100-200 mL of water from each station was filtered through Whatman GF/F filters (Ø 25 mm). Chlorophyll *a* in residue remaining on the filter was extracted by dipping the filters into 90% acetone and kept at -20 °C for 24 h. Chlorophyll *a* concentration was then determined by the spectrophotometric method (Parsons *et al*., 1984). Carbon content of different phytoplankton group sizes was analyzed. Water samples were filtered through filter paper with various pore sizes. A GF/F microfiber filter (pore size 0.7 µm) was used for filtering water samples for phytoplankton of all sizes, while micro-phytoplankton were obtained using a filter net of 20 µm. All filter papers were dried following freeze drying and then analyzed for carbon content using a CHN Analyzer (J-Science Lab, JM10). Carbon content of pico- and nano-phytoplankton was obtained by subtracting the carbon content of micro-phytoplankton from the total phytoplankton.

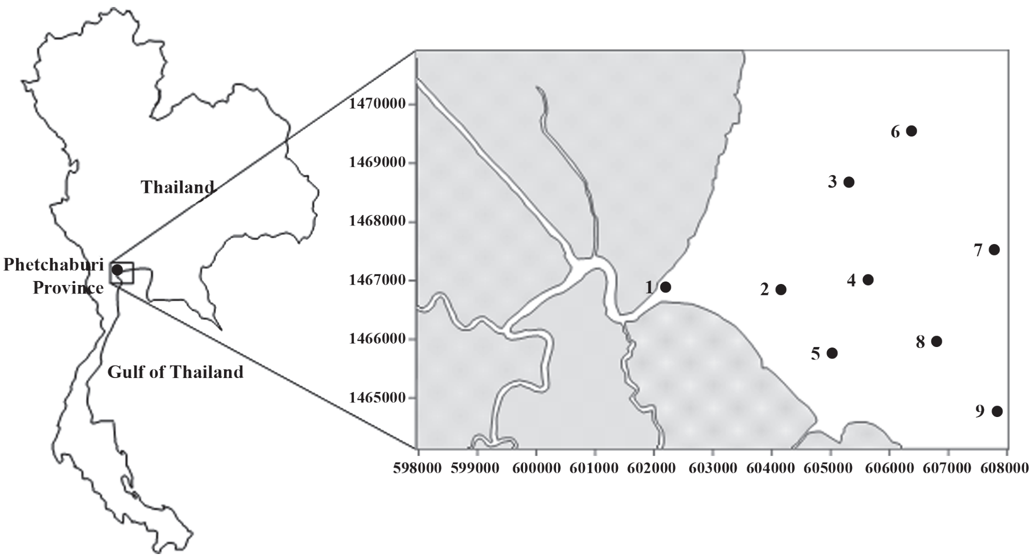


Figure 1. Sampling stations in Bang-tabun Bay, Phetchaburi Province.

### Zooplankton sampling and analysis

A bongo net with 69 µm mesh with a flow meter attached was used for collecting two replicate zooplankton samples at 50 cm depth at each station. The first sample was kept in a plastic bottle and preserved with 4% formaldehyde before analysis for zooplankton species composition and density in the laboratory. Copepods were classified by size into three groups; copepod nauplii, small copepods (0.0-0.5 mm), and medium copepods (0.6-1.0 mm). The second sample was kept in a plastic bottle and stored at a cold temperature before sample preparation for carbon and nitrogen analysis. The copepods were placed on a GF/C microfiber filter, freeze dried, and then analyzed for carbon content using a CHN Analyzer (J-Science Lab, JM10). Measured carbon content for each filter was divided by the number of copepods to obtain an estimate for each organism by size range grouping. Carbon content at each station was calculated by multiplying the measured value by the density of copepods at a specific size and summing the values for each sample.

### Energy transfer efficiency

Energy transfer efficiency of carbon content between trophic levels in Bang-tabun Bay was estimated by calculating the carbon content ratio between primary producers (phytoplankton) and primary consumers (zooplankton: copepods).

### Statistical analysis

Chlorophyll *a* and carbon content in phytoplankton were tested for normal distribution among groups using the Kolmogorov-Smirnov test (Das and Imon, 2016). Regression analysis was also performed to examine the relationship between chlorophyll *a* and carbon content in phytoplankton. Significance level for statistical analysis was set at 0.05.

## RESULTS AND DISCUSSION

### Carbon content of phytoplankton

Carbon content of all phytoplankton ranged from 563.22 to 3,492.70 $\mu g \cdot L^{-1}$. Pico- and nano-phytoplankton carbon content ranged from 451.40 to 3,213.44 $\mu g \cdot L^{-1}$, or 62.8-92.0% carbon content of total phytoplankton, indicating that pico- and nano-phytoplankton play an important role in energy transfer in this aquatic ecosystem. This percentage range concurred with results from the Western South China Sea, where size structure of phytoplankton was determined by the chlorophyll *a* concentration of 79.6-96.1% of pico- and nano-phytoplankton (Liang *et al*., 2018). Stations 6-9, located further into the bay showed lower carbon content in phytoplankton while near-shore stations (1-5) presented higher values (Table 1 and Figure 2).

### Chlorophyll *a* in the water column

Chlorophyll *a* concentration in seawater at all stations ranged from 6.59 to 20.03 $\mu g \cdot L^{-1}$. Most stations showed chlorophyll *a* concentration at higher than 10 $\mu g \cdot L^{-1}$ except St. 5 and St. 9 (6.59 and 7.09 $\mu g \cdot L^{-1}$, respectively). Carbon accounted for 73.90% of chlorophyll *a* molecules, resulting in 5.24-14.80$\mu g \cdot L^{-1}$ of carbon content in chlorophyll *a*. Carbon content in chlorophyll *a* varied from 0.26-1.31% of the carbon content in phytoplankton (Table 1).

Linear regression analysis showed a significant relationship between chlorophyll *a* and carbon content in phytoplankton at significance level of 0.05 (F=41.332, p=0.000203). Linear correlation of chlorophyll *a* (Chl $a_i$) and carbon content in phytoplankton $\widehat{C_i}$ was defined by the following equation:

$$\widehat{C_i} = 139.416 \text{ Chl } a_i$$

Table 1. Carbon content (C) in phytoplankton and copepods, chlorophyll *a* concentration, and trophic transfer efficiency (TTE) in Bang-tabun Bay, Gulf of Thailand

| Station | C of pico-+nano-phytoplankton ($\mu g \cdot L^{-1}$) | C of micro-phytoplankton ($\mu g \cdot L^{-1}$) | C of all phytoplankton ($\mu g \cdot L^{-1}$) | C of copepods ($\mu g \cdot L^{-1}$) | Chl *a* ($\mu g \cdot L^{-1}$) | C in Chl *a* ($\mu g \cdot L^{-1}$) | % C in phytoplankton's Chl *a* | TTE (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | 2,577.90 | 354.83 | 2,932.73 | 162.90 | 10.46 | 7.73 | 2,932.73 | 5.6 |
| 2 | 1,142.21 | 292.15 | 1,434.37 | 21.97 | 13.62 | 10.06 | 1,434.37 | 1.5 |
| 3 | 3,213.44 | 279.26 | 3,492.70 | 81.69 | 20.03 | 14.80 | 3,492.70 | 2.3 |
| 4 | 1,290.68 | 230.96 | 1,521.65 | 120.76 | 11.01 | 8.14 | 1,521.65 | 7.9 |
| 5 | 826.88 | 490.42 | 1,317.30 | 96.08 | 6.59 | 4.87 | 1,317.30 | 7.3 |
| 6 | 474.44 | 88.78 | 563.22 | 35.07 | 10.01 | 7.40 | 563.22 | 6.2 |
| 7 | 611.83 | 230.38 | 842.20 | 278.51 | 10.68 | 7.89 | 842.20 | 33.1 |
| 8 | 734.65 | 194.90 | 929.55 | 69.04 | 11.57 | 8.55 | 929.55 | 7.4 |
| 9 | 451.40 | 190.90 | 642.30 | 131.41 | 7.09 | 5.24 | 642.30 | 20.5 |

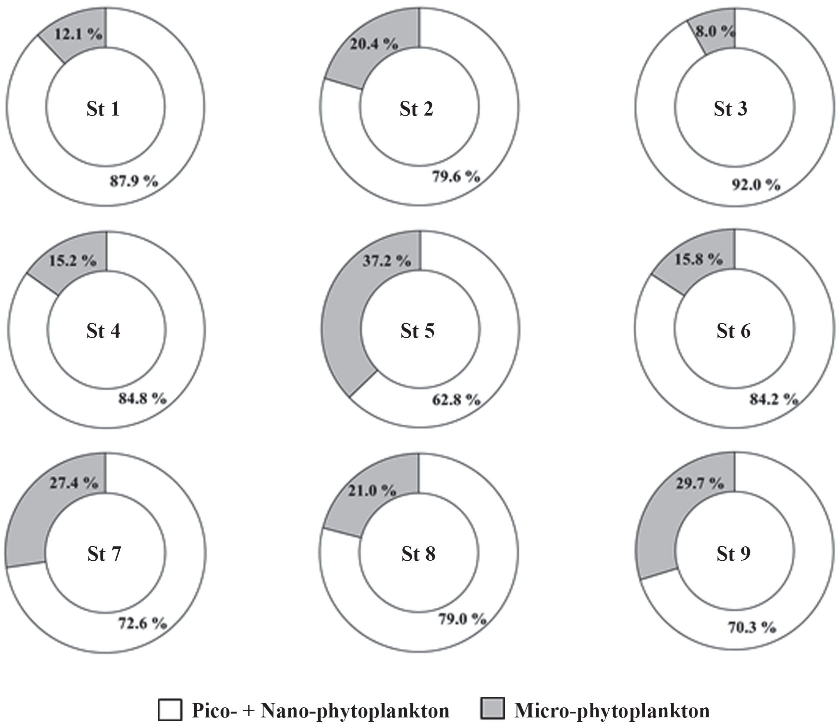


Figure 2. Carbon content percentage of different size groups of phytoplankton for sampling stations in Bang-tabun Bay, Gulf of Thailand

which was used to explain 81.8% of the variation in carbon content (Figure 3). This equation was used to estimate the carbon content of phytoplankton, and further compute primary production in the study area based on chlorophyll *a* content in the water column.

## Carbon content of zooplankton

Zooplankton in Bang-tabun Bay during September 2012 were mainly composed of the Phylum Arthropoda (61.5-100%), followed by Phylum Ciliophora and Phylum Chordata (Figure 4). Arthropoda were also the most abundant taxon in the Gulf of Tadjoura, in the Indian Ocean (Boldrocchi *et al*., 2018). In this study, copepods were found to be the primary consumers as they accounted for 66.9-100% of the total Arthropods. Copepods were dominant members in the zooplankton of many waters including the Sargasso Sea off Bermuda, the Gulf of Tadjoura, the southwestern region of the East Japan Sea, and the Senegal-Guinea maritime zone (Beers, 1966; Boldrocchi *et al*., 2018; Jo *et al*., 2017; Ndour *et al*., 2018). Density of copepods in Bang-tabun Bay ranged from 19 to 241 ind•L$^{-1}$. Naupliar stages were the most common taxa at all stations ranging from 15 to 191 ind•L$^{-1}$ or 78.9-98.4% of abundance (Table 2). In Laizhou Bay, Bohai Sea, China, copepod nauplii were also the dominant organism with abundance ranging from 0 to 140 ind•L$^{-1}$ and carbon content of 0-7 µg•L$^{-1}$ (Zhang and Wang, 2000). Large numbers of copepod nauplii were associated with phytoplankton abundance as a consequence of nutrient discharge from the Bang-tabun River in the late rainy season. This result was similar to the high abundance of phytoplankton in the vicinity of the NW Mediterranean submarine canyon by biological enrichment of slope-current waters with high concentrations of organic material and high primary productivity (Sanchez-Velasco and Shirasago, 1999).

Carbon content of copepod nauplii, small copepods, and medium copepods was 1.11, 1.33, and 2.62 µg•ind$^{-1}$, respectively. Total carbon content of copepods (including naupliar stages) of each station are shown in Table 2, ranging from 21.97 to 278.51 µg•L$^{-1}$. Carbon content of copepods in this study was much higher than was found in the Conch Reef, Florida Keyes (USA) (5.749 µg•L$^{-1}$) (Heidelberg *et al*., 2009).

## Energy transfer efficiency

Energy transfer or trophic transfer efficiency (TTE) was calculated from the carbon content of phytoplankton and zooplankton (copepods) in Bang-tabun Bay and ranged from 1.5% to 33.1% (Table 1). Results showed high TTE values in the outer-most area of the bay (Figure 5). TTE varies in coastal areas around the world, such as 5.6% in Belgian coastal waters and 3.7-12.4% in the Central North Sea (Rousseau *et al*., 2000; Jennings *et al*., 2002) due to various influencing factors. Input of nutrients into aquatic ecosystems is considered to be an essential factor affecting the variation of TTE (Kemp *et al*., 2001). Another factor is the quality of phytoplankton in terms of lipid content, especially in Bacillariophyceae and Chlorophyceae (Schulz *et al*., 2004).

Table 2. Density of copepods (ind•L$^{-1}$) in Bang-tabun Bay during September 2012

| Copepod | Density of copepod (ind•L$^{-1}$) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | St 1 | St 2 | St 3 | St 4 | St 5 | St 6 | St 7 | St 8 | St 9 |
| Copepod nauplii | 142 | 15 | 70 | 104 | 83 | 28 | 191 | 61 | 110 |
| Small copepods (0.0-0.5 0 mm) | 2 | 4 | 3 | 4 | 1 | 3 | 50 | 1 | 7 |
| Medium copepods (0.6-1 mm) | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| **Total** | 145 | 19 | 73 | 108 | 85 | 31 | 241 | 62 | 117 |

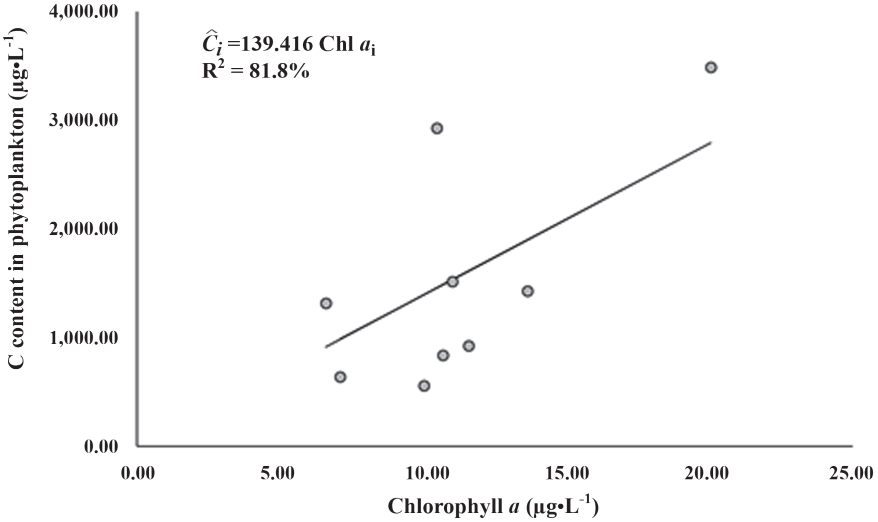


Figure 3. Linear correlation of Chlorophyll *a* and carbon content in phytoplankton sampled at Bang-tabun Bay, Gulf of Thailand

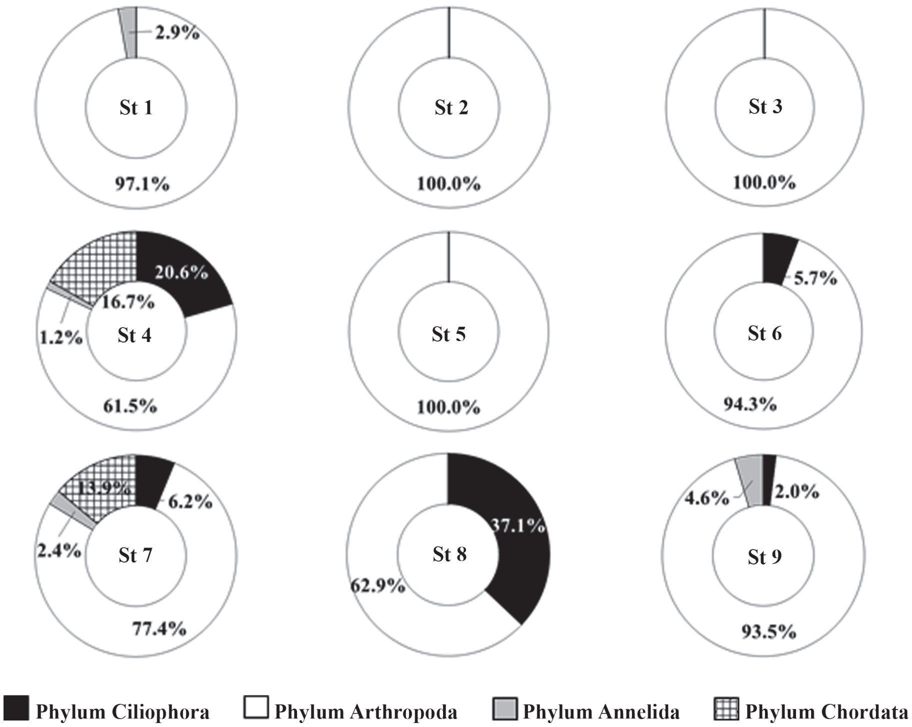


Figure 4. Zooplankton composition in Bang-tabun Bay, Gulf of Thailand

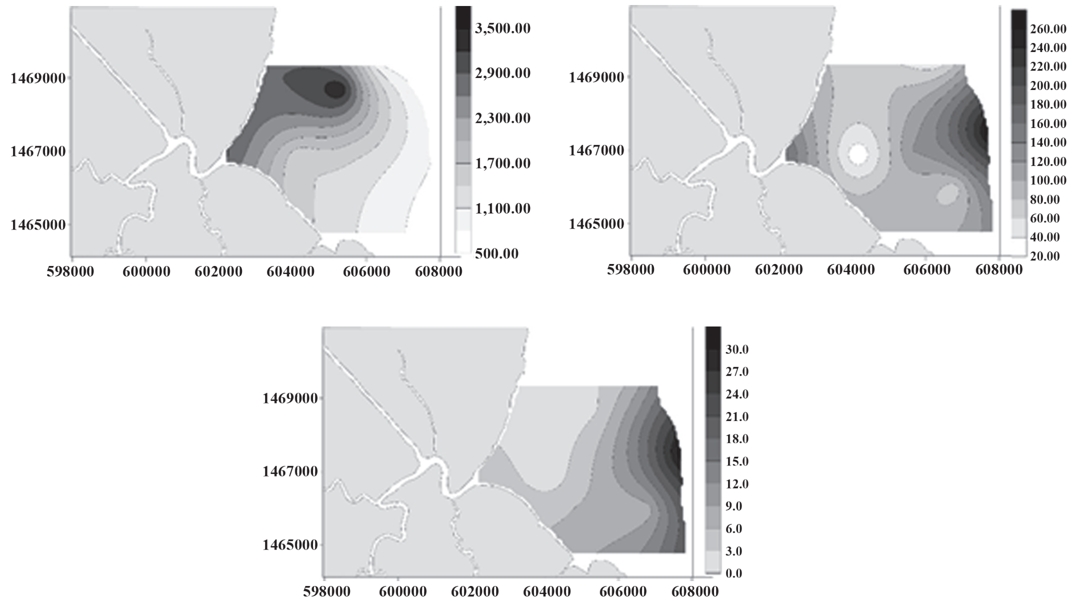


Figure 5. Carbon content of phytoplankton $\mu g \bullet L^{-1}$) (left), copepods $\mu g \bullet L^{-1}$) (right), and TTE (%) (below) in Bang-tabun Bay during September 2012

## CONCLUSION

Abundance of primary producers (phytoplankton), primary consumers (copepods) and energy transfer efficiency in Bang-tabun Bay were investigated. Pico- and nano-phytoplankton were found to be the dominant phytoplankton, with copepods the main representative of zooplankton in the study area. Energy transfer efficiency varied spatially. This data set is very important for improving methodology to predict fishery resources in tropical waters. An equation relating chlorophyll *a* to carbon content was generated to estimate the carbon content of phytoplankton when chlorophyll *a* data were available and, consequentially, enhance the study of aquatic ecosystems.

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