Nutrient Distribution in Eastern Indonesian Waters

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Abstract. Nutrients are needed for the growth of phytoplankton as a basic component in the marine food web. The concentration of nutrients in waters relates to primary productivity and it will influence fisheries stocks. So far, research on nutrients in the deep sea is rarely carried out in Indonesia. This study aims to determine water quality, horizontal and vertical distribution of nutrients in eastern Indonesian waters, which can be used as baseline data for deep-sea nutrients in Indonesia. The study was conducted from October 29 to November 15, 2017. Sampling was carried out in 20 stations with seven layers. Nutrient measurements were conducted based on Strickland and Parsons (1972). Our results showed that the concentrations of phosphate, nitrate, nitrite, ammonium, and silicate ranged from 0.000-0.060 mg/l, 0.001-0.321 mg/l, 0.000-0.009 mg/l, 0.004-0.024 mg/l and 0.085-1.090 mg/l, respectively. In general, the highest concentration of nutrients was found in Maluku Sea. The vertical distribution of nitrate, phosphate, and silicate shows that the increasing concentrations as increasing depth, except for nitrite and ammonium. The maximum nitrite concentration appears in the northern area, while the ammonium distribution has homogenous pattern.

1. Introduction

Nutrients play an important role for primary productivity as its needed especially for the growth of phytoplankton as basic component in the marine food web. Moreover, it also indicator of pollution status in waters [1,2]. The main nutrients in the waters are dissolved inorganic nitrogen, dissolved inorganic phosphorus, and dissolved silicates. Nutrient is a limiting factor in waters. The abundance of nutrients determines the fertility of waters. Nutrients will be pumped by plankton through the biological pumping process and return to the deep layers when they have died and decomposed. The distribution and behaviour of nutrient are varies depending on external supply and removal process. Sources of nutrients come from natural factors such as upwelling, mixing, regeneration of organic matter, nitrogen fixation, atmospheric deposition, and anthropogenic factors [1,3]. Currently, increasing concentration of surface nutrients is a concern as it will have negative impacts such as increasing harmful algal blooms, which will impact fish mortality and affect the ecosystem [4].

Research about nutrient distribution in eastern Indonesian waters is limited. In 1990, there was reported about nutrient distribution of the eastern Banda Sea and the northern Arafura Sea. In the eastern Banda Sea, nutrient enrichment occurred in a mixed layer [5]. Environmental conditions caused by alternating periods of upwelling and downwelling will affect nutrient distribution and primary productivity in eastern Indonesian waters [6]. This research focus on the Maluku sea, Sulawesi Sea, and Makassar Strait area in the eastern Indonesian deep waters.
The Maluku Sea is located in the eastern Sulawesi Island and reaches a depth of 4,500 m [7]. The sea is bounded to the Sulawesi Sea, Gulf of Tomini, and the Banda Sea in north, west, and south part, respectively [8]. There are several studies in the Maluku Sea that investigated about upwelling phenomenon. Upwelling phenomenon are characterized by a decrease in SST and an increase in chlorophyll-a concentration [9]. For instance, the effect of El Niño Southern Oscillation (ENSO) on the variability of SST and Chl-a and its impact on primary productivity in Maluku Sea has been investigated [8,10,11]. In addition, Atmadipoera et al. [7] has reported coastal upwelling in the Maluku Sea during the southeast monsoon due to the high transport of Ekman [7]. The highest chlorophyll-a concentrations in the Maluku Sea occurred in August [8]. The upwelling phenomenon will cause an increase in water turbidity due to the stirring of sediment from the bottom of the waters that are rich in nutrients. The nutrients that are lifted to the sea surface will be consumed by phytoplankton so that the North Maluku sea is a high primary productivity area [11].

Besides the Maluku Sea, the Southern Makassar strait (SMS) is reported as one of the upwelling regions. Sea surface temperatures (SST) is observed in August-September ranged from 24 °C – 30.34 °C, and the chlorophyll concentration in the upwelling center tends to be high [12,13]. Concentration range of chlorophyll-a in SMS region during southeast monsoon was 0.00 mg/m$^3$ – 1.144 mg/m$^3$ [14].

This study aims to determine water quality, horizontal and vertical distribution of nutrients in eastern Indonesian waters, which can be used as baseline data for deep sea nutrients in Indonesia. This study is important because it will impact fishery resources management.

2. Materials and Methods

2.1. Nutrient Analysis

The study was conducted using Research Vessel Baruna Jaya VIII from October 29 to November 15, 2017. Sampling was carried out at 20 stations in the eastern Indonesian Seas, as shown in Figure 1. Water samples were collected with Rosette Sampler at seven depths (5 m, 25 m, 50 m, 75 m, 100 m, 200 m, and 300 m). The parameters measured were phosphate, nitrate, nitrite, silicate, and ammonium. A total of 500 mL of seawater sample were put into a polyethylene bottle. Then the sample was filtered using 0.45 m nitrocellulose filter paper. Nutrients were analyzed using a Shimadzu UV-1800 spectrophotometer based on the Strickland and Parsons method [15].

![Figure 1. Map of research location in 2017. Transect A: Sulawesi Sea, Makassar Strait; Transect B: Sulawesi Sea; Transect C: Northwestern Pacific Ocean; Transect D: Maluku Sea](image-url)
2.2. Data Processing
Spatial distributions for all parameters were generated with Surfer and Ocean Data View. The observed in-situ data were analyzed for horizontal and vertical distribution.

3. Results and Discussion
3.1. Horizontal Distribution of Nutrient
The spatial distribution of nutrients at three depths (5 m, 50 m, and 75 m) can be seen in Figure 2. Overall, phosphate concentrations ranged from 0.000-0.060 mg/l. At depth of 5 m, the phosphate concentrations between stations are not much different and almost evenly distributed which ranged from 0.000-0.003 mg/l with an average of 0.001 mg/l. At depth of 50 m, the ranged phosphate concentrations was 0.000-0.007 mg/l with an average of 0.003 mg/l. The greatest concentration of phosphate was observed in the Maluku Sea. It was 0.007 mg/l compared to concentrations of 0.003 mg/l in Sulawesi Sea and Makassar Strait. On the other hand, the Sulawesi Sea has a lower phosphate concentration than in the Makassar Strait. At depth of 75 m, the phosphate concentration ranged from 0.000-0.015 mg/l with an average of 0.006 mg/l. Similar with depth of 50 m, at depth of 75 m the Sulawesi Sea has a lower concentration than the Makassar Strait and the Maluku Sea. Among all research location, the Maluku Sea has the highest phosphate concentration.

Compared to other researches, Ikhsani et al. [16] reported that phosphate concentration in Maluku sea ranged from 0.001 to 0.386 mg/l. Phosphate concentration in Southern Makassar Strait was also reported has a range of 0.001-1.89 µM [13] and the phosphate concentration in Lembeh Strait ranged from under detection to 0.007 mg/L with an average of 0.003 mg/L [17]. Other study reported that in Banggai waters, Central Sulawesi has phosphate concentration ranged from 0.001 to 0.53 mg/l [18]. On the other hand, the phosphate concentration in the Western Pacific Ocean at the depth 0–50 m was 0.53 µM [19] and phosphate concentrations in the Southern Ocean was 2.4–2.7 µM [20]. In addition, the mean mixed layer concentrations of phosphate in the Arabian Sea and Bay of Bengal were 0.2 µM and 0.04 µM, respectively [21].
|   | 5 m    | 50 m   | 75 m   |
|---|--------|--------|--------|
| A | ![Image](imageA.png) | ![Image](imageA.png) | ![Image](imageA.png) |
| B | ![Image](imageB.png) | ![Image](imageB.png) | ![Image](imageB.png) |
| C | ![Image](imageC.png) | ![Image](imageC.png) | ![Image](imageC.png) |
| D | ![Image](imageD.png) | ![Image](imageD.png) | ![Image](imageD.png) |
| E | ![Image](imageE.png) | ![Image](imageE.png) | ![Image](imageE.png) |

**Figure 2.** Spatial distribution of (A) phosphate, (B) nitrate, (C) nitrite, (D) ammonium, and (E) silicate at depths of 5 m, 50 m, and 75 m.
Nitrate is the major nitrogen compound utilized by phytoplankton for photosynthesis. Overall, nitrate concentrations ranged from 0.001 to 0.321 mg/l. At depth of 5 m, the nitrate concentration ranged from 0.001 to 0.006 mg/l with an average of 0.002 mg/l. Similar with phosphate, nitrate concentration at 5 m depth was almost homogenous in all research stations. At depth of 50 m, nitrate concentrations ranged from 0.001 to 0.016 mg/l with an average of 0.004 mg/l. The distribution of nitrate at depth of 50 m was almost as same as that of 5 m, except that the highest concentration of nitrate was found in the Makassar Strait. At depth of 75 m, nitrate concentrations ranged from 0.001 to 0.068 mg/l with an average of 0.023 mg/l. The highest nitrate concentration at depth of 75 m was found in the Maluku Sea. Compared to other researches, Ikhsani et al. [16] reported that nitrate concentrations in Southern Makassar Strait were 0.022-2.978 µM [13] while in Banggai waters nitrate concentrations were 0.004-0.381 mg/l [18]. On the other hand, the nitrate concentrations in the Western Pacific Ocean and Southern Ocean were 4.57 µM and 4.33–36 µM, respectively [19,20]. In addition, the mean mixed layer concentration of nitrate in the Arabian Sea and Bay of Bengal was 0.3 µM [21].

Overall, nitrite concentration ranged from 0.000 to 0.009 mg/l. At depth of 5 m, the nitrite concentration ranged from 0.000 to 0.001 mg/l with an average of 0.001 mg/l. The distribution of nitrite concentration at depth of 5 m is almost the same in all stations. At depth of 50 m, the nitrite concentration ranged from 0.000 to 0.005 mg/l with an average of 0.002 mg/l. Maluku Sea and Makassar Strait have higher nitrite concentrations than the Sulawesi Sea. At depth of 75 m, nitrite concentrations ranged from 0.000 to 0.007 mg/l with an average of 0.003 mg/l. Same as at depth of 50 m, the greatest nitrite concentration at depth of 75 m was found in the Maluku Sea and Makassar Strait. It was comparable with the Western Pacific Ocean where the nitrite concentration was 0.07 µM [19].

Ammonium is a compound that is converted by bacteria through the nitrogen fixation process. Some of this ammonium can be used directly by phytoplankton, but majority of bacteria convert it into nitrite or nitrate through nitrification before use. Overall, ammonium concentrations ranged from 0.004 to 0.024 mg/l. At depth of 5 m, ammonium concentration ranged from 0.006 to 0.024 mg/l with an average of 0.010 mg/l and the highest concentration is found in the Maluku Sea. At depth of 50 m, ammonium concentrations ranged from 0.005 to 0.016 mg/l with an average of 0.008 mg/l. In contrast to depth of 5 m, at depth of 50 m the highest ammonium concentrations were found in the Sulawesi Sea. At depth of 75 m, ammonium concentrations ranged from 0.005 to 0.010 mg/l with an average of 0.007 mg/l and the concentrations of ammonium were almost the same in all stations. Compared with another research in Southern Ocean, it has high ammonium concentrations in the upper water column with a range of 0.063–0.14 mg/l [20].

Overall, silicate concentration ranged from 0.085 to 1.090 mg/l. At depth of 5 m, the silicate concentration ranged from 0.085 to 0.177 mg/l with an average of 0.137 mg/l. The highest silicate concentration at depth of 5 m was found in the Maluku Sea. At depth of 50 m, the silicate concentration ranged from 0.100 to 0.177 mg/l with an average of 0.146 mg/l. The distribution of silicate concentrations is almost the same, with the lowest concentration was found in the Makassar Strait. At depth of 75 m, the silicate concentration ranged from 0.103 to 0.264 mg/l with an average of 0.174 mg/l. The highest concentration at depth of 75 m was found in the Maluku Sea. Other researches reported that in Southern Makassar Strait silicate concentration was 0.157-54.533 µM [13]. Silicate concentration in Lembeh Strait ranged from 0.087 to 1.363 mg/L in the surface water with a mean value of 0.268 mg/L [17]. Meanwhile, silicate concentration in Banggai waters was 0.055-1.308 mg/l [18]. On the other hand, the silicate concentration in the western Pacific Ocean was 7.38 µM [19]. In the Arabian Sea, the concentrations of silicate ranged between 0.5 and 1.6 µM in the upper 25–50 m of the water column [21].

The ratios of N/P and N/Si are used as indicators to determine limiting factors in waters. N/P and N/Si ratio in this research location ranged from 1.68 to 12.90 with an average 6.34 and 0.044-0.492 with an average 0.209, respectively. In addition, N/P ratio at depth 50 m ranged from 1.68 to 11.59 with a mean of 6.08 and N/Si ratio ranged from 0.57 to 2.60 with a mean of 1.01. This indicate that
nitrogen is the limiting nutrient. This ratio is higher than that of other researches. For instance, Ikhsani et al. reported that the N/P ratio in Maluku Sea ranged from 0.01 to 47.98 with a mean of 2.86 [16]. In addition, in the western Arctic Ocean the mean N/P and N/Si ratios were 2.7 and 0.3, respectively. These indicate that the western Arctic Ocean has excess phosphate and silicate which is not a limiting factor for phytoplankton growth [22]. However, in the Southern Ocean, N/P and Si/N removal ratios were 12.4 and 3.9, respectively. These are indicator of diatoms domination in the waters. High Si/N removal ratios may be due to high rate of nitrogen remineralization to silica [20]. In other part of Southern Ocean, the N/P ratio also reported has a range of 0.05 - 3.71 with a mean of 1.65. This ratio was lower than other regions. The N/Si ratio was also low with a mean of 0.76, indicating that the region was nitrate limited [23].

In the Banda Sea, variation of nutrient concentrations is influenced by season. In August, the nutrient concentration at depth < 100 m were higher than in February during the northwest monsoon. Silicate concentrations were 1-1.5 µM and nitrate is the limiting factor [5]. The Western Pacific Ocean and Eastern Indian Ocean which are oligotrophic seas have DIN 4.64 µM and 0.36 µM and DIP 0.53 µM and 0.12 µM, respectively [19,24]. N/P ratio of surface seawater in Eastern Indian Ocean have a range of 1.7–3.8, lower than Redfield ratio. The low N/P ratio of surface seawater in the investigated area indicated that nitrogen would be the limiting factor of phytoplankton growth [24]. It also happen in the Chukchi Sea where nitrogen is the limiting nutrient [25].

3.2 Vertical Distribution of Nutrients
In many world oceans, depleting nutrients in the euphotic zone is a primary limitation on ocean primary productivity. The vertical distribution of nutrients can be driven by multi-scale dynamics, including large-scale Ekman pumping, mesoscale eddy pumping, internal waves, and turbulent mixing [26]. In this study, the vertical distribution of nutrients is divided into four transects (A, B, C, and D).

3.2.1. Vertical distribution of nutrients in Transect A and Transect B
The vertical distribution of nitrate and phosphate in transect A (longitude) indicates that nitrate and phosphate concentration increases with increasing depth. In contrast, the vertical distribution of nitrite shows two patterns. First, the western pattern (119°E-120°E) has an even distribution from depth of 50 m to depth of 200 m then the concentration decreases to depth of 300 m. Second, in the eastern pattern (121°E-124°E), the concentration increases from the surface to depth of 300 m. Likewise, the vertical distribution of ammonium shows two patterns. The western pattern (119°E-122°E) has an even concentration, while the eastern pattern (122°E -124°E) has the maximum concentration at depth of 50 m.

The vertical distribution of nitrate and phosphate in transect B (latitude) is as same as in transect A where the concentration increases with increasing depth. The vertical distribution of nitrate shows that at depth of 50 m to 100 m, the concentration decreases towards the north. It is different from the distribution of nitrite, which shows that its concentration increases towards the south. The vertical distribution of ammonium shows that after 50 m, the concentration decreases until 300 m. The vertical distribution of silicates is similar with nitrate and phosphate, where concentration increases with increasing depth. However, the concentration of silicate in north tends to decrease. The vertical distribution of nutrients in Transect A and Transect B was shown in Figure 3.

3.2.2. Vertical distribution of nutrients in Transect C and Transect D
The vertical distribution of nitrate and phosphate nutrients in transect C (longitude) is as same as in transect A and B where the concentration increases with increasing depth. Nitrites and phosphates have the same pattern where the concentration decreases at depth of 0-100 m in the west (125.8°E-126°E) and increases in the east (126°E-128°E). In the vertical distribution of nitrite between depth of 0-100 m from west to east, there is an increase in concentration but at depth of 200-300 the concentration of nitrite in the west (125.8°E-126.2°E) is higher than the east (126.4°E-126.8°E). In the vertical distribution of ammonium at depth of 0-50 m, the concentration decreases further to the east, but at depth of 200 m-300 m from west to east (126.2°E-126.8°E) the concentration increases. In the vertical distribution of silicates,
although the concentration is as same as nitrate and phosphate, the concentration increases as increasing depth, while the concentration decreases from west to east.

The vertical distribution of nitrate and phosphate in transect D (latitude) is as same as in transect A, B, and C, which increases with increasing depth. In contrast, the vertical distribution of nitrite in the southern region (2°N-2.2°N) had a higher concentration than the northern region (2.4°N-2.8°N). The vertical distribution of ammonium has homogenous pattern. The distribution pattern of silicates is almost the same as nitrate and phosphate pattern. The vertical distribution of Transect C and D nutrients was shown in Figure 4. Nutrient concentrations vary regionally and seasonally because of biological process. In general, nutrient concentrations are low at the surface and increase at depth because in the surface, nutrient is consumed by primary producers and in the depth layer occurred organic material decomposition [19]. For instance, the upper layer in the Indian Ocean is strongly stratified making it poor in nutrient concentrations. The availability of nutrients in the mixed layer controls primary production in the Indian Ocean [21].
Figure 3. Vertical distribution of nutrients Transect A and B
Vertical distribution of nutrients Transect C and D
4. Conclusion
The horizontal distribution of nutrients generally shows that the Maluku Sea has a higher concentration than the Makassar Strait and the Sulawesi Sea. The vertical distribution of nutrients shows that the concentration of nitrate, phosphate, and silicate increases with increasing depth. However, nitrite and ammonium have different patterns. The maximum nitrite concentration is in the northern area, while the ammonium distribution pattern is almost evenly distributed.

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