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Jellyfish Lakes at Misool Islands, Raja Ampat, West Papua, Indonesia

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Abstract. *Purba GYS, Haryono E, Sunarto, Manan J, Rumenta L, Purwanto, Becking LE. 2018. Jellyfish Lakes at Misool Islands, Raja Ampat, West Papua, Indonesia. Biodiversitas 19: 172-182.* Misool Islands, located in southern Raja Ampat in West Papua, has dozens of anchihaline lakes (marine lakes). Three of these lakes, Lenmakana, Karawapop, and Keramat, house populations of jellyfish. This study mapped and described the characteristics of the three 'jellyfish lakes' during field surveys in October 2015 and May 2016. The lakes ranged in area from 0.5−3.2 hectares. All three lakes harbored *Mastigias papua*, Lenmakana and Keramat lakes also harbored *Aurelia* sp., and Keramat had a third jellyfish species *Cassiopea ornata*. However, at Karawapop the jellyfish were not found on the water surface during the first round of field work because of effects associated with the El Niño phenomenon at that time. As a result of the El Niño effect, at Keramat, brown *Mastigias* became white in May 2016. The three lakes have different tidal delays (30−120 min) and dampened tidal amplitude (62%) compared to the sea. The benthos was found to be dominated by bivalves (*Brachidontes* sp.), algae (*Cladophora* sp., or *Halimeda* sp.) and sponges (predominantly *Haliclona* spp. and *Tethya* spp.). In addition, species of the family Synaptidae (Holothuroidea) were abundant and spread over almost all the bottom of Karawapop Lake, while tube-worms of the Polychaeta class were identified in Keramat Lake. Although these lakes are identified as a conservation area, currently there is no management activity in Lenmakana and Karawapop Lakes, despite the fact that the lakes are growing in popularity as a tourist site. Our paper provides the baseline data for future conservation efforts.

Keywords: Anchialine Lake, conservation, jellyfish, *Mastigias papua*, Marine Lakes, Papua

INTRODUCTION

An anchialine lake (marine lake) is a body of seawater surrounded by land without connection to the sea surface, consisting of salty or brackish water that fluctuates due to tidal events (Holthuis 1973). Anchialine lakes vary widely in shape, size, depth, and distance to the sea. Around the world, there are more than 200 marine lakes with semi-submerged karst characteristics concentrated in four main locations − Bahamas, Palau, Vietnam and Indonesia (West Papua and East Kalimantan) (Dawson et al. 2009). It has been reported that Palau has 57 lakes (Colin 2009), Ha Long Bay in Vietnam has about 46 lakes (Cerano et al. 2006), Derawan Islands in East Kalimantan has 14 pieces of anchihaline habitat (Becking et al. 2011), and Raja Ampat in West Papua has at least 55 marine lakes (Becking et al. 2009; Becking et al. 2011; Becking et al. 2014). Fifteen of the lakes in Raja Ampat are in Wayag and Gam, and 40 or more in Misool.

The most renowned marine lakes are Kakaban Lake in East Kalimantan (Indonesia) and "Jellyfish Lake" in Palau. These lakes house immense populations of the perennial jellyfish *Mastigias papua* and attract thousands of tourists who want to swim amongst the jellyfish.

Investigations into marine lakes began in Palau, which has become the most researched location until now. The first scientific article by Hamner et al. (1982) concerned the characteristics of Jellyfish Lake in Palau. The characteristics observed were physical, chemical, and biological. The biological characteristics included the habit of *Mastigias* sp., which carry out a regular migration pattern each morning and afternoon. The next topic of research concerned the thirteen stratified lakes in Palau. Stratified or meromictic lake is a lake that is not mixed seasonally from top to bottom but remains permanently stratified for long period of time because of solute density (Hamner 1986 in Hamner and Hamner 1998). Stratified lakes are uncommon in tropical areas, but all the jellyfish in Palau were found in such stratified lakes. Hamner and Hamner (1998) explained factors that influence this condition.

The main studies carried out on *M. papua* have focused on its evolutionary development within the marine lakes in Palau (Dawson 2004; 2005; Dawson and Hamner 2003, 2005). Interestingly, *Mastigias* sp. is not present in all the lakes and if present, its abundance can change drastically over months or years. The change in abundance is thought to be mostly related to temperature fluctuations (Dawson et al. 2001), but the causes may differ between individual lakes.

Recently, three jellyfish lakes have been located in Misool, Raja Ampat, West Papua (Becking et al. 2014). One lake even has a population as dense as those found in Jellyfish Lake Palau, in Hang Du I Vietnam, and in Kakaban Berau Indonesia. After a brief published account by Becking et al. 2014, there have been no further publications on this subject. As tourism has been increasing in Misool, there has also been a steady increase in tourist visits to these unique lakes. Baseline information on the lakes is still lacking, as is any formal conservation management plan. In order to provide baseline data to inform conservation of the Misool Jellyfish Lakes, the study reported here aimed to document the physical conditions of the lakes (bathymetry; area dimensions; water quality; and tidal regime) and the dominant biota that inhabit the lakes.

MATERIALS AND METHODS

Study area

This research was conducted in the southeastern Misool, one of seven Marine Protected Areas (MPAs) in the District of Raja Ampat, in West Papa, Indonesia (Figure 1). The Misool MPA has an area of 343,200 ha and includes a chain of karst rock (Mangubhai et al. 2012). Three lakes within the karst chain of islands were chosen as research sites: Lenmakana, Karawapop, and Keramat. The name of each lake derives from the name of the island where the lake is located.

Procedures

Lake morphology and bathymetry

The shape of the lake was obtained using OSM Tracker, an android application. An inflatable boat was used and the tracker was turned on at a specific starting point before the boat proceeded around the lake, and then turned off when the boat returned to the starting point. Bathymetric data were obtained using a GPMAP 178/178C depth sounder. The karst walls that surround the lakes meant the GPMAP could not generate the geographic positions accurately. A hand GPS was then used to position the measured depth by GPMAP 178/178C. The boat was manually steered with oars, so it was not easy to control the boat's stability on the surface when subject to wind and currents. It was difficult to obtain consistent lane tracking to measure the depth. Therefore, as many depth measurements were taken as possible, and the measurements inputted into ArcGIS 10.1 software to create the bathymetric maps.

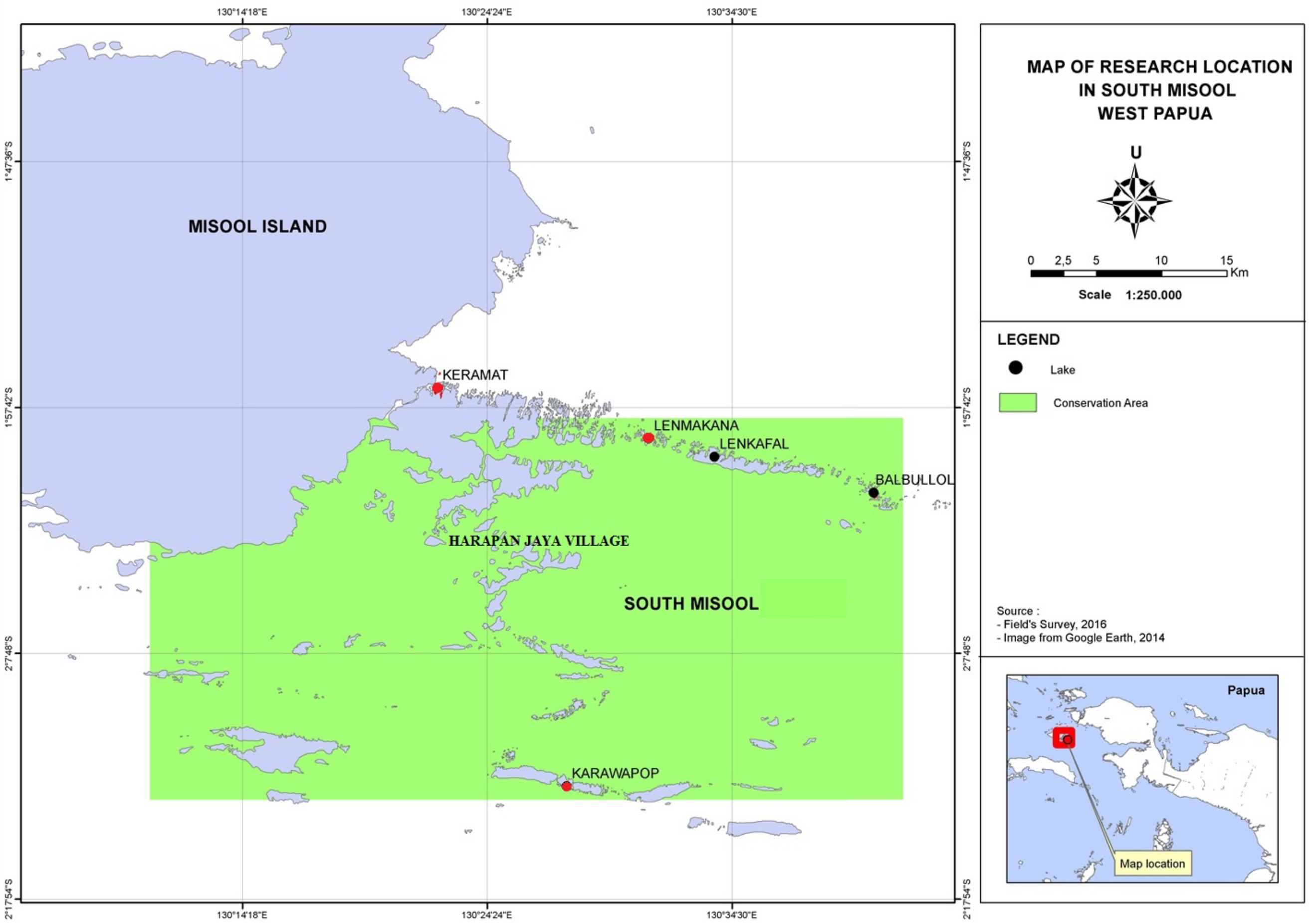

Figure 1. Lenmakana, Karawapop, and Keramat Lakes in Misool Marine Protected Area in southern Raja Ampat, West Papua

Water quality

The water quality parameters measured in this research were acidity using a pH meter (Hana Instruments HI 9025); temperature and dissolved oxygen using a YSI 550A instrument; and salinity percentage using an Atago hand-held refractometer. Measurements were performed at three different sites in each lake and the results were averaged for each lake. Vertical temperature and salinity were measured using a conductivity logger (HOBO U24-002-C). The logger was attached to a wire sling and lowered meter by per meter. An U20L HOBO water level logger was installed along with the conductivity logger to get time series data of conductivity and water level. The recording time interval was set at one hour. Due to only having 5 loggers, a long time series measurement (6 months duration) was only performed in Lake Lenmakana and on the reef in front of Harapan Jaya village. Installation in the sea aimed at comparing the results in the sea with measurements in the lake. Loggers were submerged at 2.5 m and 3.5 m depth in the lake and sea, respectively. A correction logger was installed in the air at 4 m above sea level to get the water level correction. Data collection in Karawapop and Keramat lakes was conducted during field work with the recording time interval set at 15 minutes for six hours.

Biota

Biota that lives in the lakes were visually observed and identified using reference books (e.g., Colin 2009) or articles, as well as by consulting web-based identification sites (e.g., www.marinespecies.org; www.fishbase.org; www.algabase.org; www.reefbase; www.sealifebase.org, etc.). Abundance of biota was estimated subjectively as follows: *few*, *moderate*, *many*, or *abundant*. *Few* was defined as biota were present in the lake, but not a lot. *Moderate* was defined as biota that was more easily seen in the lake, while *Many* meant biota were seen in many parts of the lake. *Abundant* was defined as biota were dominant in the lake.

Data analysis

The low accuracy of the GPS plotter made it a challenging task to determine the geographic features of the lakes. Lenmakana Lake could be seen clearly in the Google Earth image. It was observed that the GPS location of this Lake was close to the position of the lake shown in the Google Earth image. This was not the case for Karawapop and Keramat lakes. Thus, latitude, longitude, and depth (z) were plotted in the Google Earth image 2014 by ArcGIS 10.1.

Data from loggers were calibrated with water quality data from a digital multimeter. Conductivity data (µS/cm) from the logger required calibration with conductivity and temperature data from the multimeter. After that, by HOBO menu, the conductivity was converted into to salinity (ppt). Water level data (m) was obtained by converting barometric pressure from the submerged logger after making corrections for air pressure readings obtained from the logger placed in the open air. After correction, water level data reduced by minimum value of them. The result of subtraction then gets the maximum value which calculated from every 24 hours of data. Mean from these maximum value were using for tide amplitude. Also, simple statistics (maximum, minimum, mean, and standard deviation) and graphs were used in the analysis of the temperature time series data.

RESULTS AND DISCUSSION

Lenmakana Lake

Lenmakana is a meromictic lake (i.e., a stratified lake in which the water layers do not normally mix) located on Lenmakana Island (Figure 1). The time taken to reach the edge of the lake wall from the sea wall on foot was about 12 minutes and requires climbing over karst rock. This lake covers 1.25 ha and has an 18 m maximum depth. The closest edge of the lake is 55. 8 m from the sea, and there is a cave in the north of the lake (110 cm high, 250 cm wide). It is not known whether or not the cave connects to the sea or to a neighboring lake also found on the island. The water level of the lake fluctuates with the tidal cycle.

Bivalves (*Brachidontes* sp.) were abundant on the surface of the lake edge. There were five species of algae, with *Cladophora* sp. the abundant species at the bottom of the lake. The jellyfish *Mastigias papua* dominates the surface and water column of the Lenmakana Lake. There were also found moon jellyfish (*Aurelia* sp.), and the sponges *Tethya* spp. and *Suberites diversicolor*. The main substrata in the lake were stone, broken shells, and mud. Fish species found in the lake included *Caranx ignobilis, Gobiidae* spp., and *Clarias* sp. (catfish). These are not considered endemic species. They were introduced to the lake, since the normal habitat of these fish is fresh and brackish water not sea-water.

Karawapop Lake

Karawapop Lake is located on Karawapop Island in southern Misool Islands, only 23.9 m away from the sea. It takes only about 12 minutes to walk to the lake from the sea shore. There are two lakes found in Karawapop Island. The first lake is being used for the aquaculture of tilapia (*Oreochromis mossambicus*). That lake is located 89.41 m east of Karawapop Lake. The Aquaculture Lake (the name is used just for the purpose of this study) has an area of about 1.76 ha and a salinity of 5 ppt. Karawapop Lake is small in size (0.57 ha) and shallow (4.5 m). There is no significant connection with the sea, except through small holes and pores in the rocks.

Almost all parts of bottom of the Karawapop Lake are covered with green algae (*Cladopora* sp.). The lake is unique as it has many different species of sea cucumbers) (family Holothuroidea). Sea cucumbers were abundant on green algae and rocks. Mussels, *Brachidontes* sp., were also fairly abundant in the lake. There was two dominant sponges present (*Haliclona* sp. and *Suberites diversicolor).*

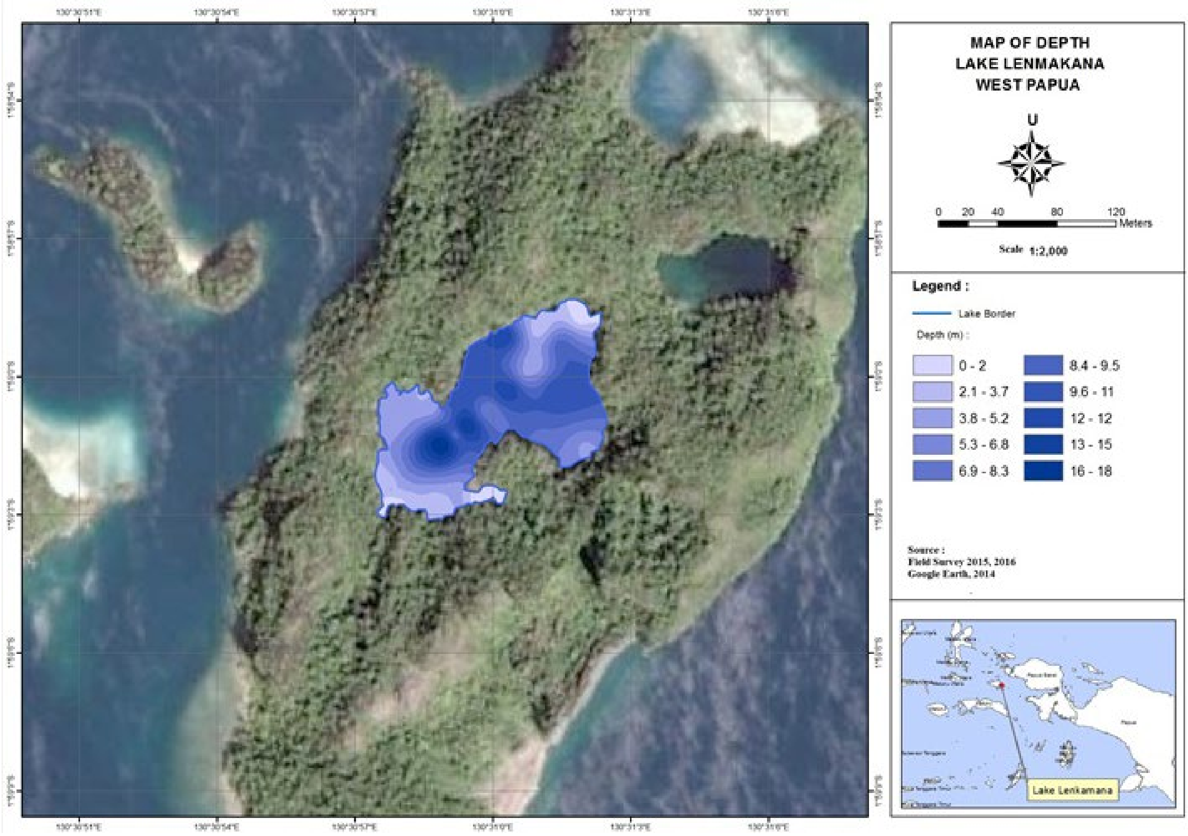

Figure 2. Bathymetry of Lenmakana Lake, Misool karst islands, Raja Ampat, West Papua

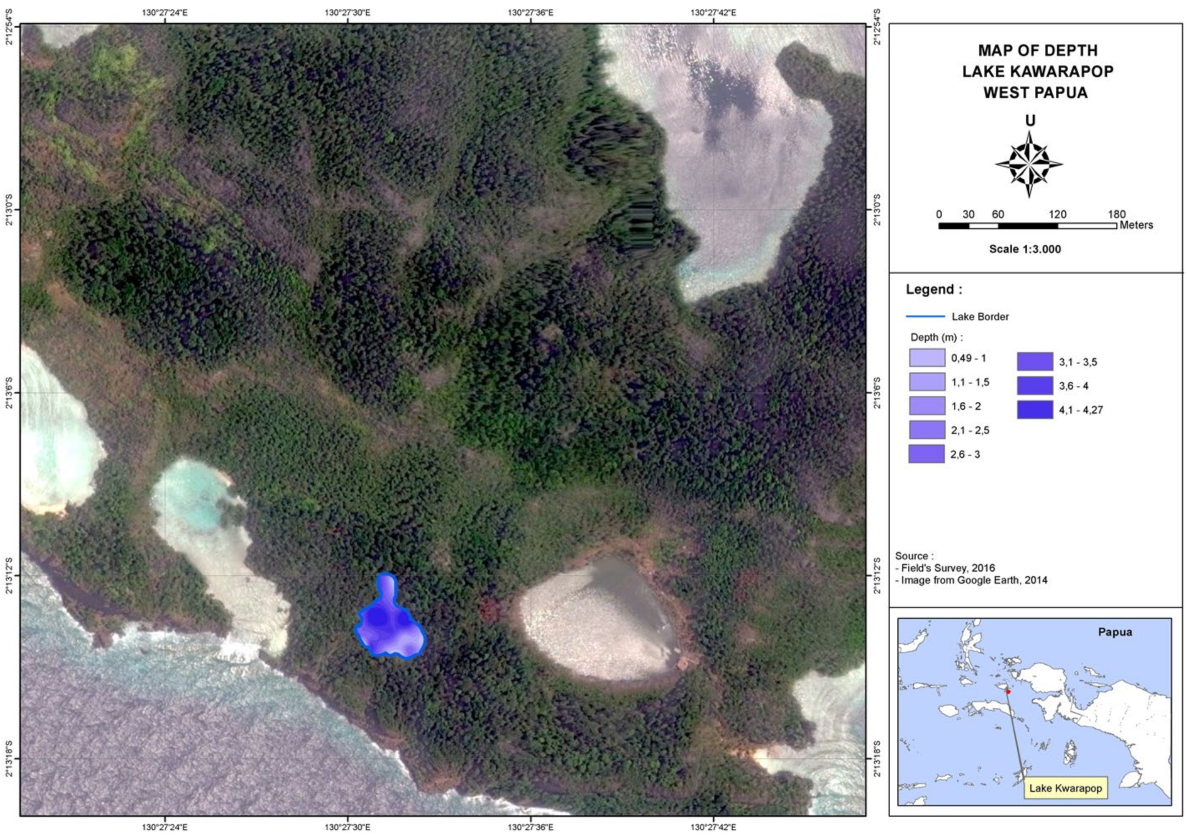

Figure 3. Bathymetry of Karawapop Lake, Misool karst islands, Raja Ampat, West Papua

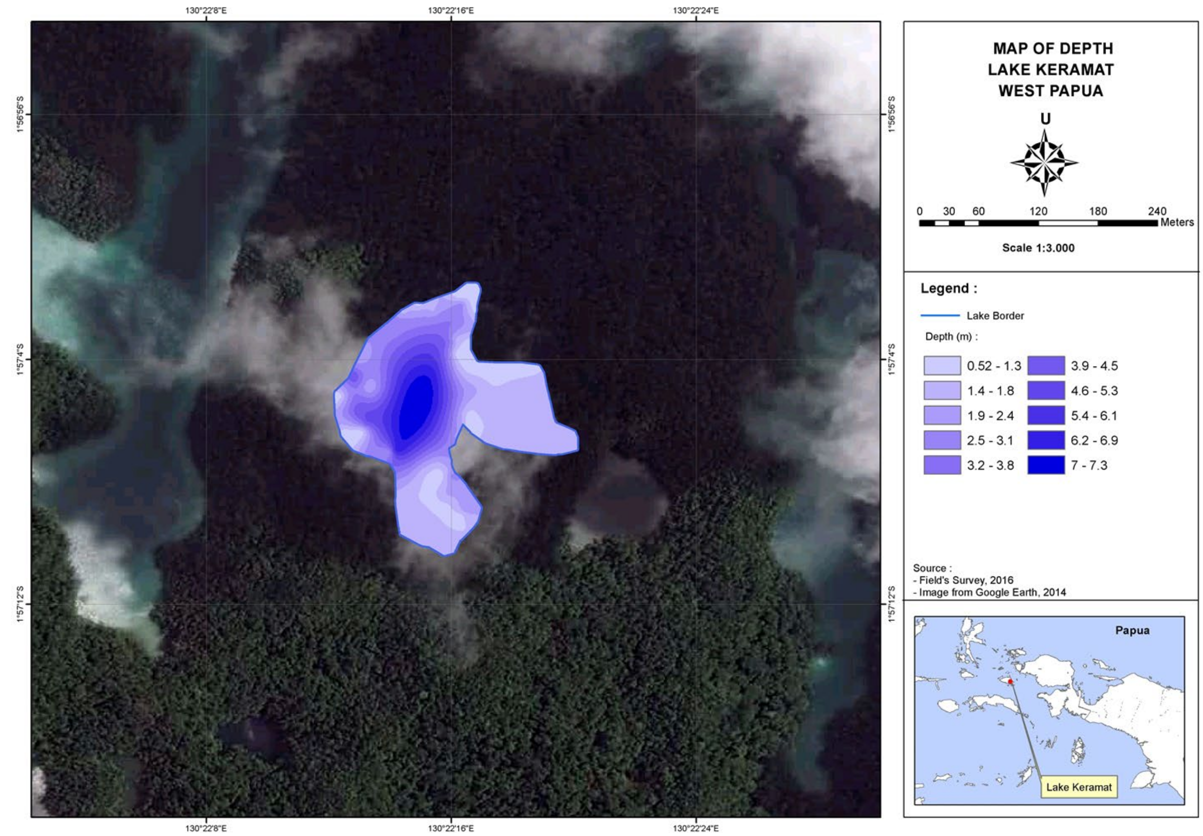

Figure 4. Bathymetry of Keramat Lake, Misool karst islands, Raja Ampat, West Papua

Medusae of the jelly fish *Mastigias* sp. were not visible on the first visit (November 2015). However, they appeared on the second visit (May 2016) in small numbers and sizes. This contradicts descriptions from local communities and Becking et al. (2014) who stated that *Mastigias* sp. is present all of the time and in large numbers. Tourists like to come to this lake to see the jellyfish and because of the ease and safety of access. It was unusual to find the blue spot mullet fish (*Moolgarda seheli)* in the lake since this species is mainly a fish of brackish waters.

Keramat Lake

Keramat Lake is located on Keramat Island, the closest island to Misool Island. It takes about 15 minutes walking to reach the lake from the sea side, with a moderate difficulty level. Different types of vegetation are found there including rattans, ferns, palms, *Terminalia catappa*, *Barringtonia asiatica* and other typical coastal forest vegetation. Keramat Lake size is 3.23 ha, and the point closest to the sea is 109 m from the shoreline. It is connected to the sea by a cave. The width and height of the mouth of the cave are 4.1 m and 3.4 m, respectively, and the maximum depth is 7.3 m. The east side of the Lake is the shallowest, and is mostly covered by mangroves (*Bruguiera* sp.) on a mud substrate.

What was unique about this Lake was the presence of three species of jellyfish, *Mastigias papua*, *Cassiopea ornata*, *Aurelia* sp., as well as a ctenophore. Interestingly, some the *Mastigias* sp. jellyfish were brown in color in October 2015 but white in May 2016 (Figure 9).

Halimeda sp. was the dominant algae in Keramat Lake, while *Brachidontes* sp. was the dominant mollusk. There were also three types of tube worm present in abundance in the lake. Shells and skeletons of worms formed part of the lake substrate. The only fish found in the lake was the trevally *Caranx ignobilis.*

Water quality

Water quality parameters and other physical characteristics of the three lakes are summarized in Table 1. The highest water temperature was recorded at Lenmakana Lake, but its salinity was considerably lower than at the other two lakes. The vertical temperature profiles (Figure 5) do not show a permanent stratification such as in the lakes in Palau, except at Karawapop Lake, which showed a warmer temperature and lower salinity at the surface than in the deeper layers. It happened at north and south part. These conditions because measuring time were coincided with time when cooler sea water flew into lake. Salinity profile showed this sea water flew at 2 m depth with more saline plot.

The temperature time series over 6 months of data collection showed that the maximum and the average temperatures in Lenmakana Lake were higher than those in the sea. The coldest temperatures were in the sea. The maximum temperature recorded in the lake water was 1.64ºC higher than the maximum recorded in the sea, while the minimum temperature in the lake exceeded by 1.28ºC the minimum recorded in the sea. The average temperature in the lake was 0.98ºC warmer than the average in the sea. Furthermore, the daily sea surface temperatures fluctuated more than that of the lakes. Nevertheless, the overall different standard deviations in the sea and in the lakes were small (0.03ºC). They almost have the same dispersion of mean temperature. Naturally, rainfall and air temperature greatly affect the water temperature in the ocean because the ocean is more open with no barriers to the influence of the atmosphere. The average water temperature in the sea and lake showed a similar trend in the fluctuations over time from the beginning to the end of the recording (see Figure 6).

Relative to the difference in temperature, the differences in daily average salinity between the lake and sea were larger (1.71 ppt). The sea salinity decreased gradually over a period of two and a half months from about 28.6 ppt to about 26.5 ppt; however, salinity in the lake was stable over the same period (Figure 7). Similar to the case for temperature, atmospheric conditions with its effect on precipitation, evaporation, and currents can produce greater changes in the salinity of the ocean than in the salinity of a protected marine lake. Of course one reason for it different in depth where logger installed. Logger installed at 1 m deeper in the sea would read more saline water than in the lake.

Misool water has a semidiurnal tidal type with almost the same peak position (Figure 8). The amplitude of the tide in Lenmakana was 0.98 m, compared to 1.58 m in the sea. The tide range in Lake Lenmakana was about 1.2 m, compared to 2.26 m in the sea. The tidal delay in the Lenmakana Lake is about 1 to 2 hours (Figure 8). Karawapop and Keramat had a shorter delay, i.e. 30 and 45 minutes (Table 1).

Table 1. General features of the marine jellyfish lakes on the Misool karst islands of Raja Ampat, West Papua. Water quality parameters were measured by portable instruments. Tide (water height) was measured by loggers.

Character	Lenmakana	Karawapop	Keramat
Size (ha)	1.25	0.57	3.23
Maximum depth (m)	18	4.5	7.3
Distance to the sea (m)	55.8	23.9	109.0
Temperature (ºC)	28.90-29.30	28.30-29.00	27.50-27.90
Salinity (ppt)	26-29	32	32
Oxygen (mg/L)	5.2	3.3	-
pH	7.30	7.32	7.22
Tide delay	1-2 hours	30 minutes	45 minutes
Tidal amplitude (m)	0.98	-	-
Relative tidal amplitude to Sea (m)	1/1.6		
Presence of mangroves	-	-	Yes
Connection to sea	Cave	Crack and fissures	Cave

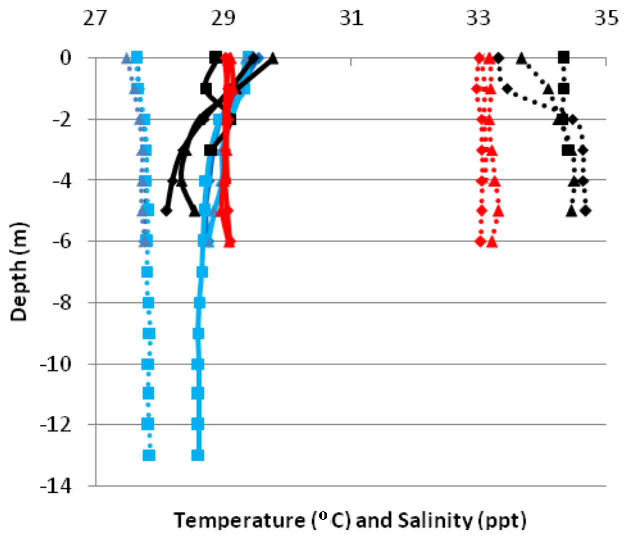

Figure 5. Water temperature-depth profiles of three lakes at Misool karst islands, Raja Ampat, West Papua measured by loggers. Solid lines represent temperature and dashed lines salinity. Blue = Lenmakana Lake, black = Karawapop Lake, red = Keramat Lake. ◊ for the south, □ for the middle, and Δ for the north.

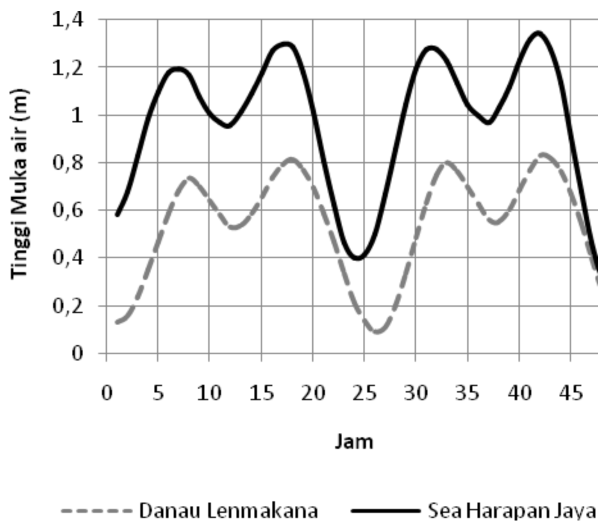

Figure 8. Water level from water level logger at 2.5 m at in the sea and in Lake Lenmakana, Misool karst islands, Raja Ampat, West Papua, recorded between 8 December 2015 (08:00 AM) to 10 December 2015 (08:00 AM).

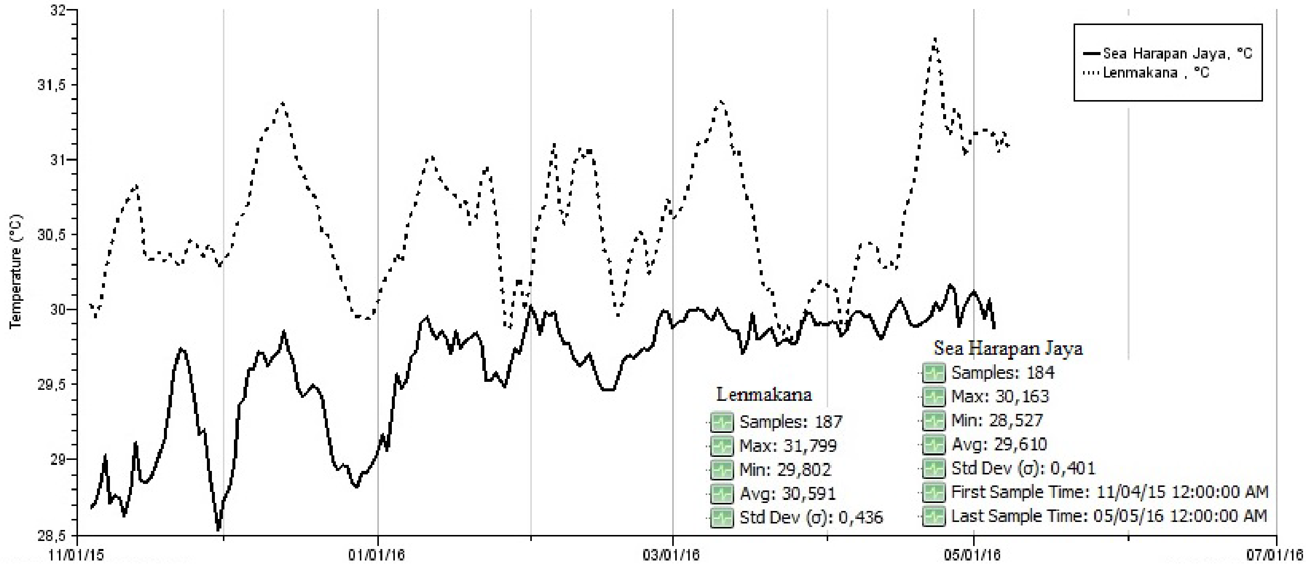

Figure 6. Time series of temperature at Sea Harapan Jaya and Lemakana Lake at Misool karst islands, Raja Ampat, West Papua. The loggers were installed at 3.5 and 2.5 m depth respectively. Data points were the daily average from 24 hours of data recording

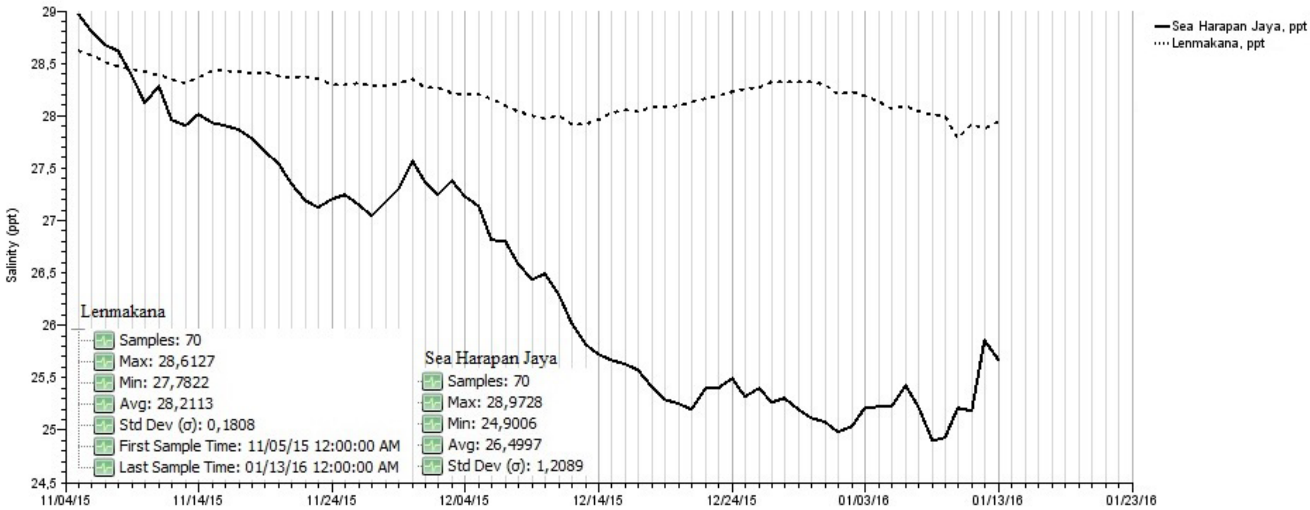

Figure 7. Time series of salinity at Sea Harapan Jaya and Lenmakana Lake at Misool karst islands, Raja Ampat, West Papua. The loggers were installed at 3.5 m and 2.5 m, respectively. Data points were the daily averages from 24 hours of data recording

Biological communities

Table 2 shows the dominant biota identified in all the three lakes. Some biota are apparently abundant in one lake but might not be found in other lakes. Likewise, more species of one genus may be present in one lake but less in other lakes.

Discussion

Physical character

Based on the size, basin depth and salinity, marine lakes in this study cannot be classified according to the anchialine habitat classification outlined by Santodomingo (2009). The three lakes do not meet the criteria of "lake" defined as > 10 ha in area, a basin depth of 10 m, and salinity ranges from 23-27%. Likewise, they cannot be classified as "lagar", for which the criteria are that the area is <1 ha, basin depth is <5 m, and salinity is 26%. Nor do the lakes in this study conform to criteria that characterize a "blue pool" i.e. with size <200 m^2, a deep basin, and with 11% salinity Therefore, it seems that the marine lakes in Misool's karst islands do not fit any of the three categories defined by Sanodomingo (2009). The jellyfish lakes in the three Misool Islands are small and of relatively shallow depth.

Colin (2009) stated that lake formation is closely connected with sea level rise. The deeper the lake, the earlier the pool was formed. Therefore, lakes in Misool Islands are younger than in Palau, such as Tketau Lake that has a maximum depth of 60 m. Tketau Lake gradually started to form about 12,000 years ago, while shallower lakes began their development approximately 4,000 to 5,000 years ago (Colin, 2009). Thus it would seem that the jellyfish lakes of the Misool karst islands should be categorized as young-age lakes.

Being located at a distance very close to the sea, the jellyfish lakes have a close relationship with the sea. The longest tidal delay is in Lenmakana Lake. It is possible that the tidal delay is actually shorter than the 1-2 hours we have recorded in this study (See Table 1), because the time interval set for recording on the logger was one hour in order to get longer time series data. Except for jellyfish lake at Mecherchar in Palau, tidal delays in Misool Islands lakes are shorter than in Palau and in Maratua off the north coast of East Kalimantan (Table 3). The maximum tidal amplitude in Lenmakana Lake is 0.98 m, that is approximately 62% smaller than that in the sea. Lenmakana and Keramat lakes have surface caves large enough for sea water to enter and leave. Apparently, there are no caves or other natural water canals in Karawapop Lake that might represent a connection between the lake and the sea. However, there are cracks and fissures in very close proximity to the sea.

It can be seen from Table 1 and 3 that, the physical characteristics of the jellyfish lakes are diverse. Therefore, there is no consistent feature in the environments of the lakes that could be considered as definitive criteria for the presence of jellyfish in the lakes. Vertical stratification occurs in Karawapop Lake (Figure 5). The temperature drops gradually (by 1.5°C), from the surface to a depth of 4 m. Meanwhile, the northern profile is rather cooler. Salinity increases as the depth increase. The north salinity profile is a bit higher, in synchrony with the low temperature at 4 m (bottom). Since Karawapop is a shallow lake, it is impossible to form layer stratification. The vertical stratification occurs because sea water comes into the lake and brings cooler and more saline water.

From the temperature and salinity parameter data recorded in Figure 5, the Jellyfish lakes in Misool Islands can be regarded as homogenous. However, at Lenkamana Lake there was a black layer. According to Hamner and Hamner (1998), meromictic lakes are identified as having anoxic conditions (a lack of O_2) at specific depths. This lake decreased oxygen at 5-8 m and afterward anoxic (Becking LE, 2017, pers.com). Unfortunately, we did not carry out vertical oxygen measurements. Karawapop and Keramat lakes are holomictic lakes, i.e. lakes that are mixed in the entire water column, from surface to the bottom. Shallow depth results in the entire depth being stirred by gusts of the wind. This condition is the same as in Hang Du I in Vietnam, which only has 8 m depth.

Table 2. Biota dominant in the three marine lakes investigated in Misool karst Islands, Raja Ampat, West Papua

Biota	**Lenmakana**	**Karawapop**	**Keramat**
Algae			
Chondrus crispus	+	-	-
Cladophora sp.	++++	++++	-
Codium intricatum	++	-	-
Gelidium pusillum	+	-	-
Caulerpa serrulata	+	-	-
Halimeda sp.	-	-	+
Mollusc			
Brachidontes sp.	++++	+++	+++
Clithon diadema	+	-	
Lataxiena fimbriata	++	-	++
Codakia punctata	-	-	+
Trochus californicus	-	-	+
Tellina scobinata	-	+	-
Fish			
Caranx ignobilis	+	-	+
Gobiidae	+	-	-
Moolgarda seheli	-	+	-
Clarias sp.	+	-	-
Jellyfish			
Mastigias papua	++++	+	+++
Aurelia sp.	+	-	++
Cassiopea ornata	-	-	+
Ctenophore	-	-	+
Sponges			
Tethya spp.	+++	-	+++
Haliclona spp.		+++	+++
Suberites diversicolor	-	+	-
Holothuroidea			
Euapta godeffroyi	-	+++	-
Opheodesoma serpentina	-	+++	-
Synapta spp.	-	++++	-
Tube worm			
Filogranella spp.	-	-	++++
Sabellidae	-	-	++++

Note: -: absent, +: few, ++: moderate, +++: many, ++++: abundant

Table 3. Characteristics of marine lakes with jellyfish at Palau, Vietnam, and Indonesia

Parameter	Jellyfish Lake-Mecherchar Palau	Clear Lake-Mecherchar, Palau	Big Jellyfish Lake-Koror Palau	Goby Lake-Koror Palau	Hang Du I-Halong Bay Vietnam	Berau01-Kakaban Indonesia	Berau03- Haji Buang, Maratua Indonesia
Size (ha)	6.1	4.5	4.5	2.1	0.8	390	13.8
Maks depth (m)	30	30	38	15	8	12	17
Dist to the sea (m)	200	260	210	110	50	120	325
Temp (ºC)	28-31	29.5-30.5	30-31	29-31	29.1	29-31.5	29-30
Salinity (ppt)	26-29	20-23	22-25	23	7	23-24	26-28.5
Oxygen (ppm)	5-6	5.5	6	5	6.56	5.9-6.6	-
pH	-	-	-	-	8.08	7-7.8	7.3-7.8
Damp from Lagoon/ sea	1/3	1/4	1/4	1/3	-	1/10	1/2.2
Tide delay	1 hr 40 min	3 hr	2 hr	2 hr 30 m	-	3 hr 30 min	2 hr 30 min
Amplitude	-	-	-	-	0.5-1	0.19	0.75
Jellyfish	*Mastigias Aurelia*	*Mastigias*	*Mastigias Aurelia*	*Mastigias*	*Mastigias*	*Mastigias, Aurelia, Cassiopea*	*Mastigias*
Mangrove	+	+++	-	-	++	+++	+
Connection with sea	2 large surf & 1 small tunnels	Mangrove	Crack, fissures	1 tunnels	Undetectable	Low	Low (porous)

Sources: Becking et al. (2011), Colin (2009), Dawson and Hamner (2005), Hamner and Hamner (1998), Santodomingo (2009)

From 57 lakes in Palau, there are 12 meromictic lakes (Hamner and Hamer 1998). *Mastigias* sp. is found in four of these lakes. Palau has many meromictic lakes, although it is in a tropical region. This is due to several factors: Palau has a high annual rainfall (3300-3500 mm $^{-1}$); its lakes are mostly surrounded by mangroves with roots that probably cause tidal currents to become gentle, limiting the effects of tidal mixing; and there is midwater mixing by tidal jets from outside (Hamner and Hamner 1998). Rainfall in the Misool karst islands is not as intense as in Palau, except for July and August when monthly rainfall reaches 443.2 mm and 311.7 mm, respectively. Mangrove vegetation is present only in the Keramat Lake but only in small areas. Mangroves in Keramat Lake are concentrated in the east, while the cave giving entry to sea-water is in the West. Therefore, the mangroves do not cause weakening of the tidal influence, one of the steps in the processes leading to stratification. If stratified water column by black layer existed, weakening of the tidal current possibly does occur at Lenmakana Lake because the cave that experiences the tidal ebb and flow, does not come from the sea directly. It could be that the small lake situated beside Lenmakana Lake buffers the tidal current coming from the sea. The weak current would perhaps allow for stratification in Lake.

Mastigias sp. *and high-temperature*

The jellyfish genus *Matigias* is only found in warm water (Hale 1999). The medusae maintain a mutualistic symbiosis with zooxanthellae that need sunlight for photosynthesis. However, high temperatures are reported to bleach the scyphistomae stage due to temperature-sensitivity of their symbiosis with zooxanthellae, and also to reduce strobilation of the scyphistomae. Dawson et al. (2001) reported that at 34ºC in the El Nino of 1998/1999, zooxanthellae mortality sped up and their density reduced. Also, the high-temperature reduced the population of the ephyrae stage while small medusa did not survive.

In contrast to the effects of high temperature, the specific effect of variation in salinity is not clear. Salinity of 7 PSU did not appear to be influential in the life of *Mastigias* in Lake Hang Du I in Vietnam (Ceranno et al. 2006). The *Mastigias* population did not disappear even in the high salinity period of December 1998 to April 1999 at Palau. High tolerance of variation in salinity is suggested by the jellyfish' daily vertical migration from the surface to 18 m depth which results in their exposure to diurnal salinity difference of 8 PSU (Dawson and Hammer 2003).

At the time of the field work October 2015 in our study, there were not found *Mastigias* sp. but Mei 2016 only a few were found in Kawarapop Lake. We hypothesize that this may have been caused by the El Nino conditions that started in June 2014 (NOAA 2015, 2017). NOAA (2017) reported that a global El Nino peak occurred in November-December 2015 and became the strongest El Nino ever. In July-December 2015, intensive sea surface temperature (SST) increase occurred in the central to eastern Pacific. This condition extended to the Indian, Pacific and Atlantic basin in October 2015, marked by global coral bleaching. Furthermore, from January to May 2016 until August 2016, the SST in Indonesia and the Coral Triangle area was classified as at the Alert Level 1 (NOAA, 2016). Measurements with local loggers confirmed satellite measurements. Unfortunately, there is no time series data for water temperature in Lake Karawapop.

Mastigias sp. did not appear in Palau during the El Nino time of 1998/1999 (Dawson et al. 2001). Ceranno et al. (2006) also reported that *Mastigias* sp. were unseen in Hang Du I Lake, in September 2003 due to a rise in temperature of 3°C compared with spring 2003.

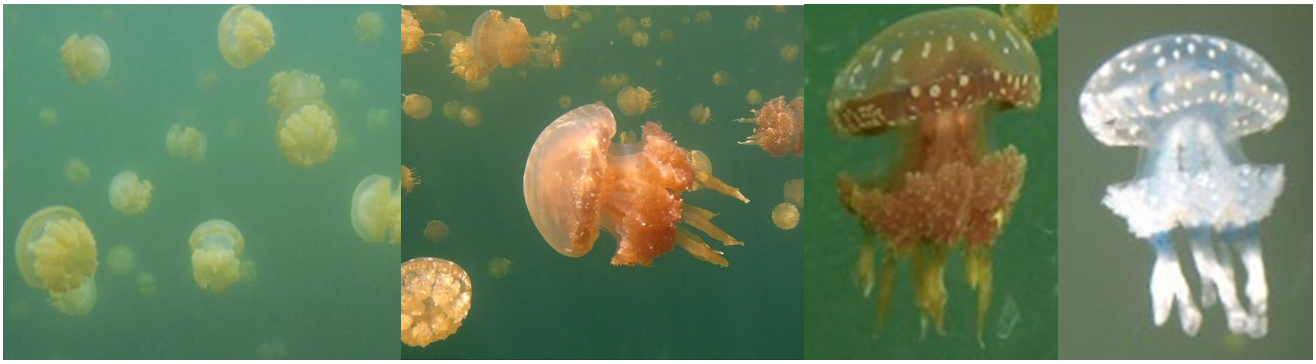

Figure 9. *Mastigias papua* at A. Lenmakana Lake, B. Karawapop Lake (Photo by LEB), C. Keramat Lake at October 2015, and D. Keramat Lake at May 2016 (Photo by GYSP)

Associated with rising SST in the mixolimnion layer of the Keramat Lake, white *Mastigias*, i.e., *Mastigias* without zooxanthellae, were found in Keramat Lake (Figure 9D). Small white population of medusae, apparently without zooxanthellae, and mostly less than ~25 mm size, were also reported in Palau, during the El Nino cycle of May 1997 (Dawson et al. 2001). The conclusion arrived by Dawson et al. (2001) is that the occurrence of small white *Mastigias* sp. was likely strobilate aposymbiotically than bleach post-strobilation. The bleached animal typically exhibited some remnants of zooxanthellae. In fact, microscopical analysis found no remnants of zooxanthellae in preserved jellyfish sample. So these white jellyfish were not because of bleaching. We need more study about this phenomenon since white jellyfish at Keramat had a brown spot and varying in size from small and big.

Sub-species of Mastigias sp.

Mastigias sp. jellyfish in Lenmakana Lake show a slightly different morphology from the *Mastigias* sp. in the two other lakes (Figure 9). Their oral arms in Lenmakana Lake are shorter than in the other two lakes. Colin (2009) and Dawson et al. (2009) noticed that the *Mastigias* sp. of the ancestral lagoon had oral arms longer than in *Mastigias* sp resulting from evolution in the lakes. In other words, *Mastigias* sp. evolution in Karawapop and Keramat lakes appears to be younger than in Lenmakana. Dawson and Hamner (2005) and Dawson et al. (2009) revealed that morphological evolution was caused by the isolation of a lake, as the lakes flooded 12,000 then 5,000 years ago. This isolation was the cause of different characteristics of marine lakes, such as depth, area, physical and chemical structure. As the lakes become more isolated, jellyfish are more likely to develop into subspecies, such as indicated by the presence of five new sub-species of jellyfish *Mastigias* sp. in different lakes in Palau (Dawson 2005). The level of isolation of the lake can also be a factor determining the existence of other jellyfish in the lakes, although, which level of isolation determines which particular species can survive is unconfirmed. *Aurelia* sp. inhabits some lakes with abundant *Mastigias* sp. Commonly they are found below the depth zone of *Matigias* sp., about 5 m below the surface (Colin 2009).

Conservation management

There is currently little management of visitors to jellyfish lakes in Misool. Small and shallow marine lakes, close to villages, are utilized for daily domestic activities such as toileting, trash disposal, or aquaculture. For example, in Karawapop Lake, a shelter and warehouses have been built to facilitate people reaching the lake. Initially, they were built to support the aquaculture activities in the area. In Lenmakana Lake, an emergency facility, an artificial ladder from natural materials, was constructed but this was later damaged by weather.

Usually, tourists come to the jellyfish lakes via live-aboard dive boats from Sorong. There is no information about the number of tourists that visit the lakes annually, and no one to control tourist activities during the visits. This is of concern given how fragile the marine lakes are. Snorkeling, wearing of sunscreen and/or urination can affect the water quality and the presence of biota. Dawson et al. (2001) showed that a level of sunscreen concentration of 10^{-6} g ml^{-1} in the water can cause the death of *Mastigias* after 30 hours. The small size of lakes in Misool Islands would be more sensitive to any interference caused by humans or by natural phenomena such as El Nino. Therefore, in order to conserve and protect the ecosystem of the lakes in Misool Islands, site visits should be well-managed involving the government and the local community. Establishing management systems, including fees charged to tourists, may create positive incentives for communities to better protect and manage the marine lakes.

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