

# REPRODUCTIVE ASPECTS OF THE TROPICAL ABALONE, *HALIOTIS ASININA*, FROM SOUTHERN LOMBOK WATERS, INDONESIA

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## ABSTRACT

The main objective of this study was to determine reproductive strategy including major spawning season of tropical abalone (*Haliotis asinina*) from southern Lombok waters, Indonesia. Gonad bulk index, maturity stages and oocyte size frequency distribution were applied to document gonadal development and major spawning season. The results of this study show that *H. asinina* in southern Lombok waters displayed year-round spawning with a high proportion occurring in August - November, when gonad index dropped to a lower level and high proportion of partly spawned and/or spent ovaries occurred in the population. Gonad development and spawning in males and females occurred synchronously. The correlation between gonadal development and environmental factors are described and discussed.

**Keywords:** gonadal development, *Haliotis asinina*, Lombok waters.

## INTRODUCTION

Abalone (*Haliotis*) is a herbivorous marine mollusc belonging to the class Gastropoda, family Haliotidae. It is a very popular food, therefore, both demand and the market price are high. There are approximately 100 species of abalone distributed around the world (Bevelander, 1988), with larger species found in the temperate regions and smaller species in the tropical and Arctic regions. Seven species of abalone are found in Indonesia, i.e., *Haliotis asinina*, *H. varia*, *H. squamosa*, *H. ovina*, *H. glabra*, *H. planata*, and *H. crebrisculpta* (Dharma, 1988). *Haliotis asinina* is the largest of the tropical abalone species and occurs throughout the Indo-Pacific, including eastern Indonesian waters.

In temperate and subtropic regions, abalone generally has a well-defined seasonal breeding periodicity that varies according to species and water temperature. For example, *H. asinina* spawns only during late summer on Heron Reef, eastern Australia (McNamura and Johnson, 1995). In contrast, in tropical region, such as, in Thailand and Philippines, *H. asinina* is known to spawn almost continuously throughout the year (Jarayabhan and Paphavasit, 1996; Capinpin *et al.*, 1998).

Although some aspects of the reproductive biology of *H. asinina* in Thailand and the Philippines have been described, it is still important to study the reproductive strategy of the species in relation to its local environmental condition, including sea temperature, air temperature,

sunshine-hours (number of actual hours of sunshine as a percentage of possible number in any month), rainfall and tidal range. These environmental variables may affect the process of gonad maturation and spawning.

No study has been performed on the reproduction aspects of tropical abalone (*H. asinina*) in Indonesia. Therefore, it is necessary to obtain basic knowledge of reproduction aspects in this species to underpin the management of the wild stock and provide the necessary background for fisheries management and the development of an aquaculture industry. This study is designed to document the cycle of gonad development and major spawning season for the tropical abalone (*H. asinina*) in southern Lombok waters, Indonesia.

## MATERIALS AND METHODS

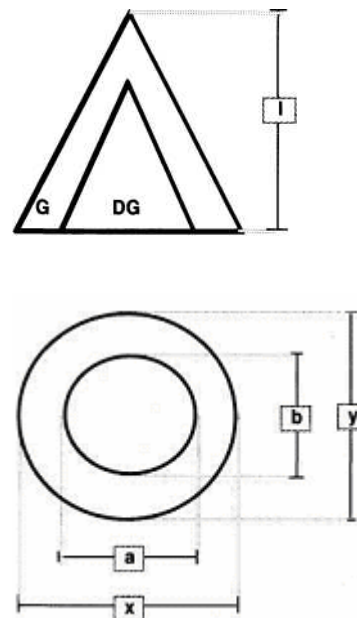
### Collecting of samples

Abalone samples were collected fortnightly over a one year period from coastal areas of southern Lombok Island, Indonesia (Latitude  $8^{\circ}50'-9^{\circ}00'S$  and Longitude  $116^{\circ}00'-116^{\circ}30'E$ ). Collection was carried out during low tide around new moon and full moon, by removing intertidal abalone gently from their shelter under rocks, dead coral or within crevices. Fishermen kept the collected abalone in a net bag for periods of 2-3 hours. The abalone in the bag were kept moist by covering them with algae (*Gracilaria* spp). On the beach the abalone were then transferred into an aerated plastic container then transported to laboratory.

A minimum of 20 abalone having shell length  $>50.0$  mm were taken randomly for gonad development study. Before measurements were taken, the abalone were put on a dry towel to absorb water from around the body and shell. The abalone were, dry weighed to the nearest 0.1 g and then their shell length were measured to the nearest 0.1 mm. They were then dissected to remove the gonad and viscera from the body and the shell. Conical appendage and visceral coil of the abalone were separated from the shell and subjected to gonadal measurement.

### Gonad index

The conical appendage (gonad and digestive gland) was separated by making a cut near the base of the visceral coil. Both the width and height of the conical appendage were measured in a section through the midpoint of the conical appendage (Fig. 1). Gonad area at the section was estimated by subtraction of the digestive gland area from the conical appendage area.



**Figure 1.** Top: Schematic drawing of conical appendage showing gonad (G) and digestive gland (DG), 1 = length of conical appendage. Bottom: Schematic drawing of a transverse section taken at the midpoint of the conical appendage, x = width of conical appendage, y = height of conical appendage, a = width of digestive gland, and b = height of digestive gland (Tutschulte and Connell, 1981 in Hahn, 1989a).

Gonad index was calculated using the modified Gonad Bulk Index (GBI-tc) of Tutschulte and Connell (1981). This method produces an accurate estimate of the change in gonad volume and is a good indicator for gonad maturation in *H. rufescens*, *H. fulgens*, *H. corrugata* and *H. sorensen* (Tutschulte and Connell, 1981), and in *H. asinina* at present study.

The GBI-tc is calculated by dividing estimated gonad volume (EGV) by body weight (BW). The EGV was calculated as follows (Tutschulte and Connell, 1981):

$$EGV = \frac{\pi}{96} * [8 * (x + y)^2 \frac{(x + y + a + b)^3}{(x + y)}]$$

where / is length of conical appendage, x is width of conical appendage, y is height of conical appendage, a is width of digestive gland, and b is height of digestive gland (Fig. 1).

Gonad index was calculated for each abalone of both sexes. The mean value and standard error (SE) were plotted against the time of sampling. The spawning was predicted to occur at the time when the levels of gonad index of both sexes dropped sharply from a maximum.

### Gonad histology and maturity stage development

After measurement for GBI-tc determination, gonads were preserved in Bouin's solution for at

least 24 hours. The gonadal tissue was then processed using standard histological procedures (Humason, 1979). The tissues were embedded in paraffin wax, sectioned at 6-7 μm with a Cambridge Rotary Microtome, and mounted onto slide, then stained with haematoxylin and eosin. The slides were covered with a cover glass then examined under the microscope. The stage of maturity of the gonad were assigned to criteria modified from Wood and Buxton (1996) and Capinpin *et al.* (1998). The criteria used to determine gonadal maturity stage is presented in Table 1. Five maturity stages, i.e. **previtellogenic** (immature and proliferati ve), **maturing**, **ripe**, **partly spawned** and **spent** were set out.

### Oocyte size measurement

Oocyte size was measured from histological sections by an image analysis system. A binocular microscope which was connected to a Macintosh computer to scale the measurements and store the data using software (NIH image 1.61 for Macintosh). The perimeter of fifty randomly selected oocytes were measured from every ovary

**Table 1.** Criteria used to assess gonadal maturity stages in *Haliotis asinina* (modified from Wood and Buxton, 1996 and Capinpin *et al.*, 1998).

Stage	Male	Female
Immature	The gonad is characterised by little or no germinal epithelium between the outer epidermis and the digestive gland	The same as male
Proliferative	Spermatogonia measuring about 5 μm diameter closely associated with the trabeculae.	Oogonia measuring about 5-10 μm in diameter closely associated with the trabeculae. Oogonia of about 10-15 μm in diameter form clusters on trabecular walls and become stalked.
Maturing	Early gametogenic stage present around the tubules. A thin layer of spermatids or spermatozoa may be present	A newly maturing ovary contains stalked oocytes measuring about 25-30 μm in diameter. Vitellogenesis is initiated in this stage. A late maturing ovary has stalked teardrop-shaped oocytes >50 μm in diameter.
Ripe	The testis is densely packed with spermatozoa.	The ovary contains oocytes >120 μm in diameter. Mature oocytes are free from the trabeculae, with a mean diameter of about 135 μm.
Partly spawned	The testis has obvious spaces around the tubules where spermatozoa have vacated. Other areas appear as ripe.	The ovary contains reduced densities of mature oocytes. Gonad lumen is partially collapsed with folded trabeculae. Moderate number of ripe oocytes still present, some areas still densely packed.
Spent	Gonad lacks ripe gametes and displays only slight gametogenic activity. Gonad lumen is collapsed with folded trabeculae or tubules. Ovary may have a few residual of large (mature) oocytes, but .small previtellogenic oocytes are dominant.	The same as male

sample to determine the oocyte diameter. Oocyte diameter (D) was calculated as follows:

$$D = 2r \quad r = \frac{P}{2}$$

where r is radius, and p is perimeter.

Oocyte growth was determined by plotting the mean oocyte size against the time of observation. Oocyte size frequency data from ovaries with the same maturation stage were pooled to follow oocyte development.

### Environmental factors

Environmental factors such as sea surface temperature, salinity, pH, air temperature, sunshine-hours, wind speed, tide levels and rainfall were recorded. Sea surface temperature, salinity and pH were measured in situ during field sample collections from February 2000 to January 2001 using a mercury thermometer, a salinometer and buffered pH paper, respectively. Sea temperature, salinity and pH were measured to the nearest 0.5°C, 0.5 psu and 0.5, respectively. *In situ* measurement was done in at least three different locations (Kute, Ujung and Gerupuk) in southern Lombok waters.

Secondary data on tide levels were obtained from the Indonesian Naval Hydro-Oceanographic Office, while data on sunshine-hours, rainfall, air temperature and wind speed were obtained from the Meteorological Station, Department of Agriculture in Lombok. The average values of monthly environmental data were calculated based on the daily record from February 2000 to January 2001.

### Statistical analyses

A three-way analysis of variance (ANOVA) was performed to test for significant differences between the mean values of gonad index for lunar periods (new moon and full moon) and sexes. The gonad index data were first tested for normality using an option test of 'Normal Probability Plot'. Square root transformation was done for the GBI-tc. The Scheffe Post Hoc test

was used to identify significant differences between the mean values of each variable.

Pearson product moment correlation coefficients (r) were computed to test for any relationships between the changes in gonad index with the environmental variables (sea temperature, air temperature, rainfall, sunshine-hours, salinity, tidal ranges and wind speed).

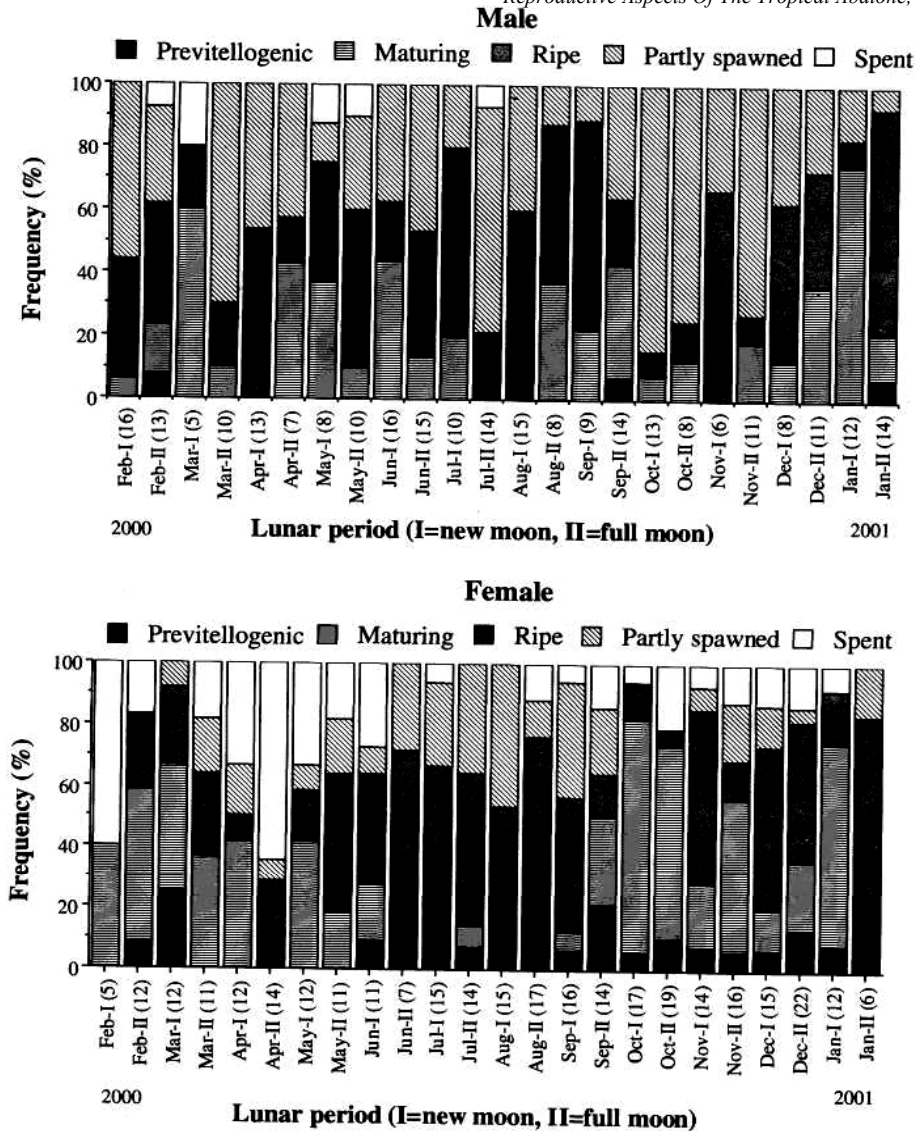
All tests were performed using the software packages Microsoft-Excel 98 (Microsoft Corporation) and DataDesk 4.1 (Data Description, Inc. Ithaca, New York, United States). The statistical significance level (P) was set at 0.05.

## RESULTS

### Gonad maturity stage development

Fig. 2 shows the occurrence of each gonad maturity stage of *H.asinina* during fortnightly sampling (I = new moon and II = full moon). In males, previtellogenic testes (10 %) were found only in February II, September II and January II. Maturing testes fluctuated in fortnightly sampling (5 - 70 %), except in July II and August I in which there were no maturing gonads. Ripe testes occurred in every fortnightly sampling. The occurrence of ripe testes increased from March I (20 %) to peak levels in August I - September I (65 %), dropped to a low level in October I (10 %) and increased again in November I (60 %) and fluctuated thereafter. Partly spawned testes were found throughout the year, but in March I there were only spent stage (about 20 %). A high percentage of partly spawned testes (70 - 80 %) occurred in October I - November II. A low percentage of spent testes (5 - 20 %) were found in February II, March I, May I and II, and July I.

In females, a low percentage of previtellogenic ovaries (5 - 20 %) were found throughout the year, except in March II - May II. Maturing ovaries decreased from February II (50 %) to a low level in June II - August II (0 %), increased again to a peak in October I (70 %), and fluctuated thereafter. Conversely, the frequency of ripe ovaries increased from February II (20 %) to a peak in July I (55 %), decreased to a low level in



**Figure 2.** Occurrence of each maturity stage in fortnightly sampling for testes (top) and ovaries (bottom) of *Haliotis asinina* in southern Lombok waters, eastern Indonesia. The sample sizes are shown in parentheses.

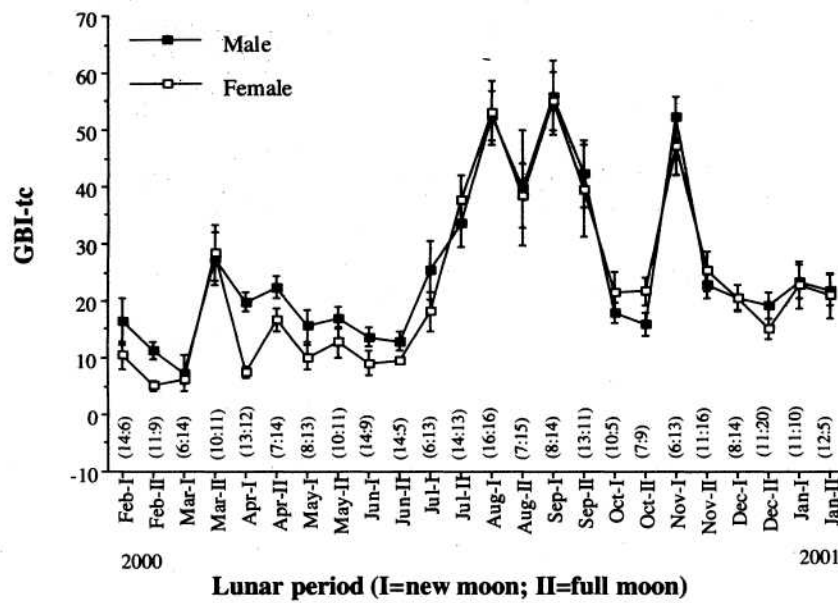
October II (10 %), and fluctuated thereafter. Partly spawned ovaries were found throughout the year, except in February and October, with a high percentage in July and August (40 - 45 %). A high percentage of spent ovaries were found in April II (60 %) and fluctuated in a low level (5 - 20 %) through the rest of the year.

**Gonad index development**

Fig. 3 shows the seasonal changes (fortnightly) in mean GBI-tc for male and female *H. asinina* from southern Lombok waters from February 2000 to January 2001. Changes in male GBI-tc

tended to be parallel to the changes in the female GBI-tc. There were no significant interaction between lunar periods and sexes (data not shown ANOVA P = 0.527). This results show that the seasonal changes in male and female GBI-tc were in synchronous mode.

GBI-tc for both sexes fluctuated at a low level from February I to June II. Sharp increases in GBI-tc occurred through July and peaked in August I and September I. GBI-tc decreased rapidly in September II and dropped to a low level in October II. The second significant peak of GBI-tc occurred in November I and fluctuated



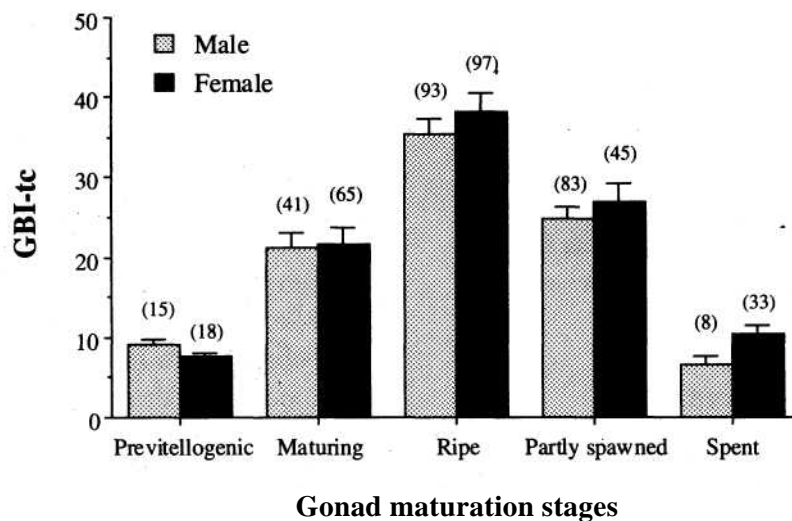
**Figure 3.** Fortnightly changes in GBI-tc for male and female *Haliotis asinina* in southern Lombok waters, Indonesia. Values are mean and SE. The sample sizes (males:females) are shown in parentheses.

at a low level thereafter. Analysis of variance for GBI-tc (data not shown) showed that mean GBI-tc were not significantly different between lunar periods ( $P = 0.795$ ), but significantly different between sexes ( $P < 0.001$ ). The mean value of GBI-tc varied between approximately 7-56 and 7 - 48 for males and females, respectively. However, male and female *H. asinina* in southern Lombok waters could reach GBI-tc value as high as 122.5 and 157.1.

Plotting the GBI-tc values against the gonad maturity stages (Fig. 4) revealed that the mean value of GBI-tc increased slowly during the maturing stage, peaked at the ripe stage and then declined to a low level in the spent animals.

### Oocyte size frequency distribution

The oocyte size frequency distribution was dominated by a cohort of small oocytes in



**Figure 4.** GJI-tc of *Haliotis asinina* from southern Lombok waters, Indonesia as a function of gonad maturity stage. Values are mean and SE. The sample sizes are shown in parentheses.

February through May (data not shown). The number of small oocytes decreased as larger size classes increased in frequency in June through September. In October again a cohort of small oocytes dominated the population with a second increase in the frequency of larger oocytes in November and December, and in January small oocytes were dominant in the population with a few larger oocytes remained.

Mean oocyte diameter fluctuated within lunar periods (new moon and full moon) (Fig. 5) reflecting a fortnightly breeding cycle. Mean oocyte diameter increases in February II, June II, July II, October I and November I. Marked increases in mean oocyte size occurred in the period of July - August and November - December (Fig. 5) showing a clear peak of spawning time for a yearly breeding cycle.

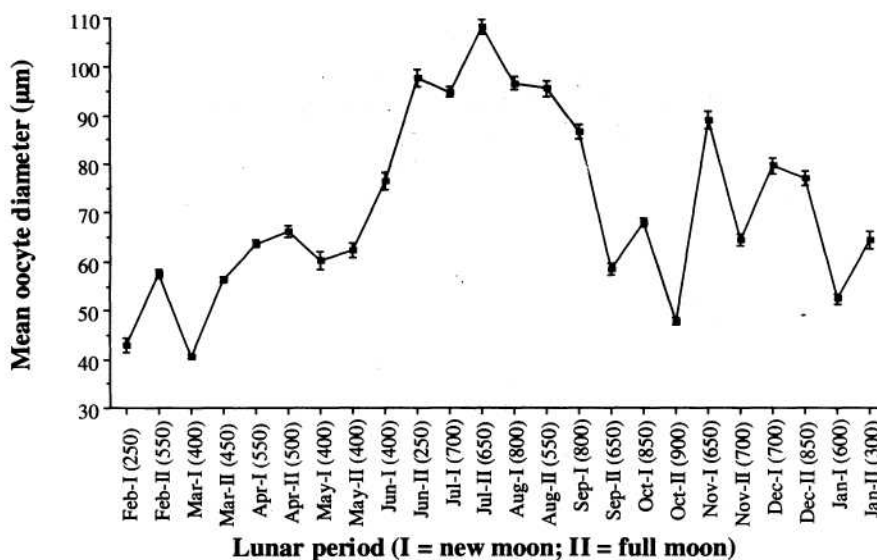
Grouping oocyte diameter data from ovaries at the same maturity stage (Fig. 6) shows that proliferative ovaries contained oocytes < 40 μm and a size class of 20 μm dominated the cohort. The maximum size class of oocyte diameter increased to 110 μm in maturing ovaries as vitellogenic oocytes occurred in this stage. In maturing ovaries, oocytes with a diameter of 70 μm dominated the cohort. A wider range of oocyte size classes occurred in ripe and partly spawned

ovaries with a small percentage of large oocyte (diameter up to 190 μm) present in these stages.

### The correlation of reproductive periodicity with environmental factors

Fig. 7 shows the changes in sunshine-hours, rainfall, number of days with rain, and air temperature. The percentage of sunshine-hours increased from February to April with rainfall also increasing. After April, the rainfall dropped considerably to a low level in August and September as Lombok entered the dry season. Conversely, after April, sunshine-hours continued to increase, peaking in August, and decreasing thereafter as the rainy season started. Changes in rainfall tended to be parallel to the changes in the number of days with rain.

Maximum air temperature increased slightly during the rainy season and decreased slightly during the dry season. However, the minimum air temperature decreased continuously through the later part of the rainy season and during the dry season. During the dry season, the air temperature was slightly cooler because of the influence of the "eastern monsoon", when the wind blows from a south-easterly direction, bringing cold air from the Southern Hemisphere. The minimum air



**Figure 5.** Mean oocyte diameter plotted against the time of observation. Values are mean and SE. SE bars are not shown when values were smaller than the size of the symbol. The sample sizes are shown in parentheses.

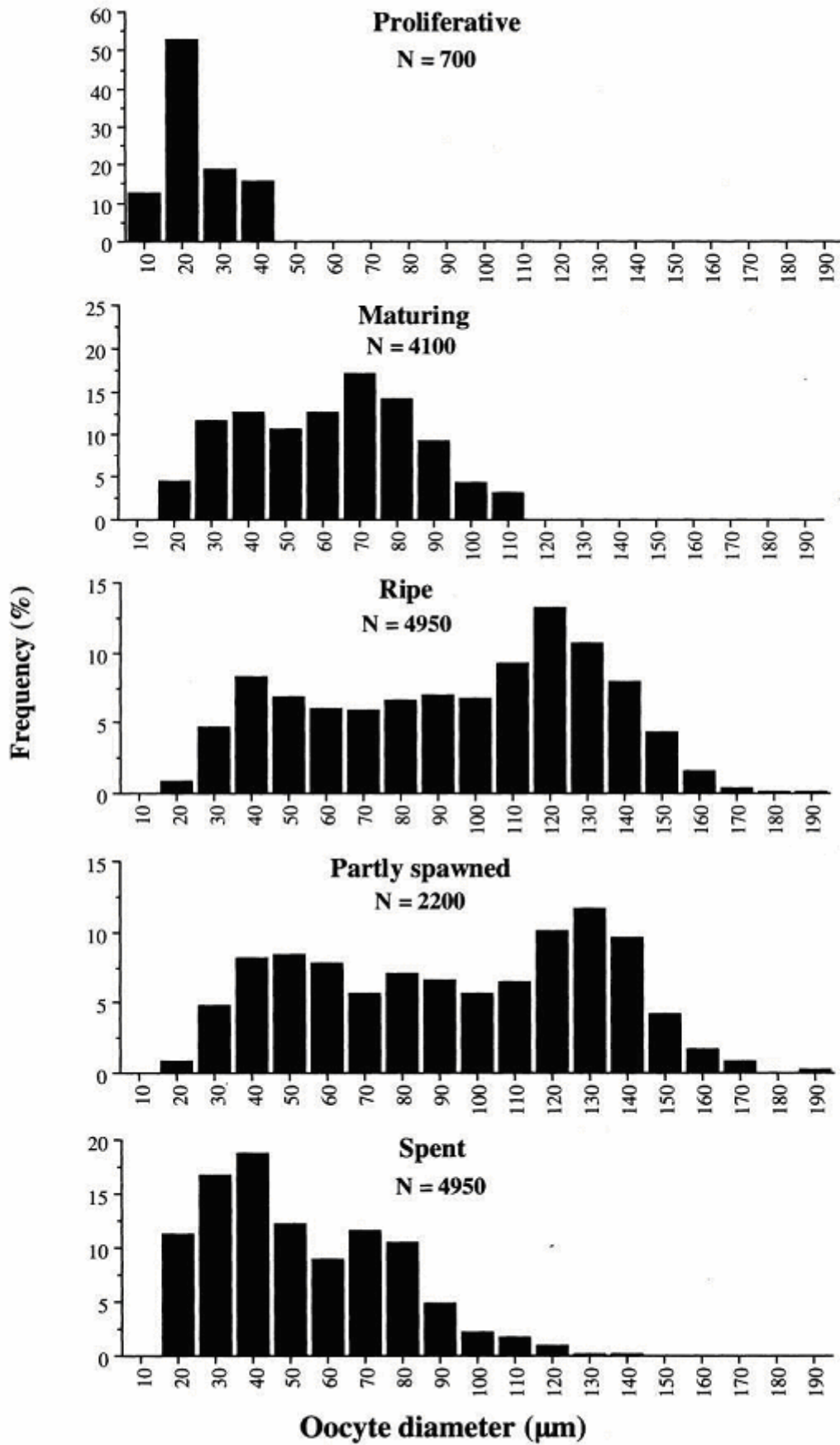
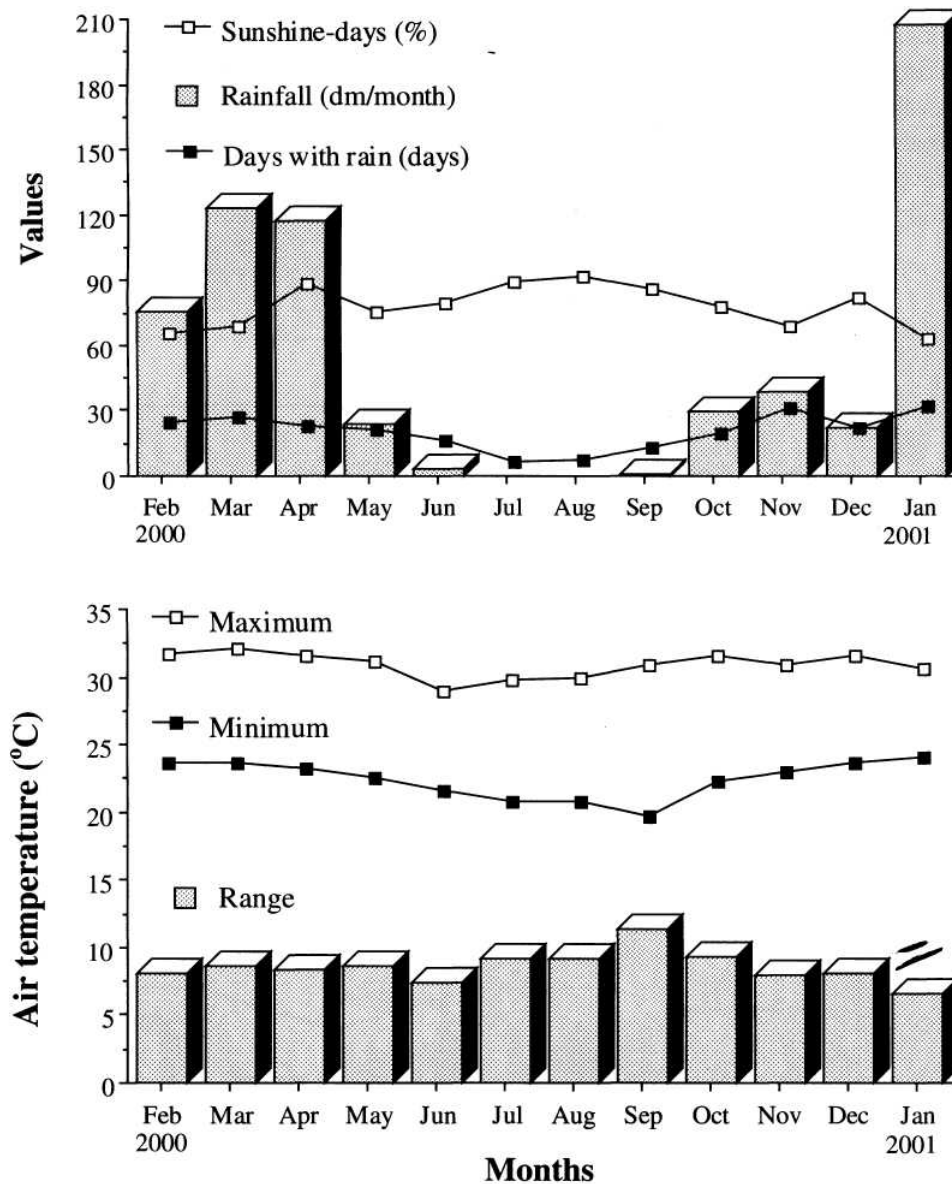


Figure 6. Histogram of size frequency distribution of oocytes from *H. asinina* ovaries at the same stage of maturity.



**Figure 7.** Changes in sunshine-hours, rainfall (1 dm=10 mm), and number of days with rain (top) and air temperature (bottom) in Lombok, Indonesia from February 2000 to January 2001.

temperature decreased considerably from February to September, resulting in a larger fluctuation in air temperature. The ranges between minimum and maximum air temperature peaked in September and decreased again until January (Fig. 7).

During the study, sea conditions did not change extensively. In general, sea surface temperature was largely constant throughout the year, as well as for salinity and pH. Sea surface

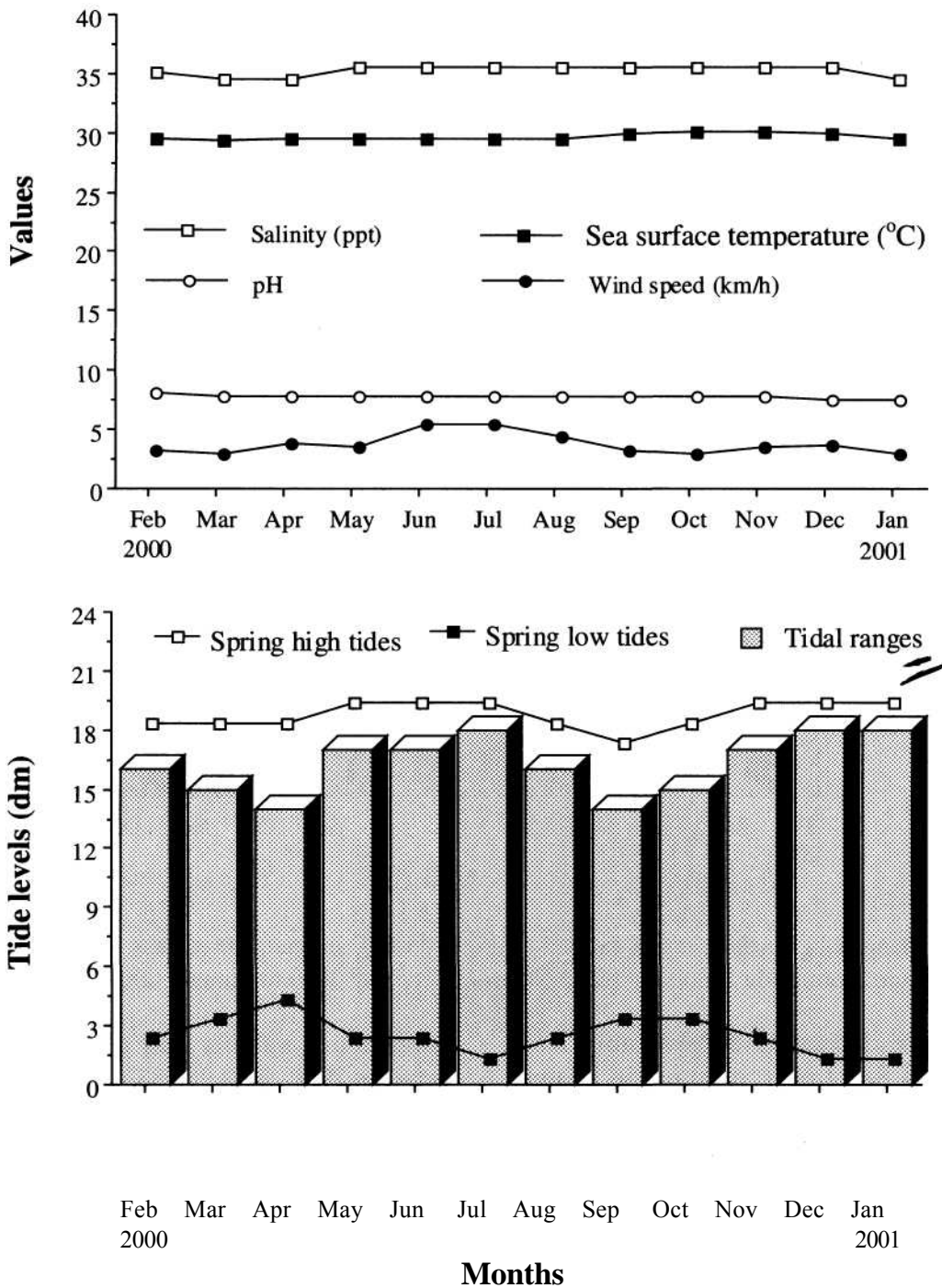
temperature, salinity and pH levels ranged between 29.0 - 29.5 °C, 33 - 35 psu, and 7.0 - 7.5, respectively (Fig. 8).

The monthly average wind speed at 2 m from the ground increased from about 2.3 km.hour<sup>-1</sup> in January to a peak of about 3.8 km.hour<sup>-1</sup> in August. Wind speed was higher during the eastern monsoon (July - September) than during the western monsoon (December - February).

Spring low tides dropped to a minimum level in July while spring high tides were at their highest level, resulting in a large range between low and high tide levels. The range of tide levels became smaller when spring high tide dropped into a minimum level in September while the spring low tide was high. Lower tide levels were noted in

December - January for the western monsoon and in July for the eastern monsoon (Fig. 8).

Correlation analysis (Pearson Product-Moment Correlation) between the mean values of GBI-tc and environmental factors revealed that GBI-tc were significantly correlated negatively ( $P < 0.05$ ) with minimum air temperatures ( $r = -0.682$



**Figure 8.** Changes in salinity, pH, sea surface temperature and wind speed at 2 m from the ground (top) and tide levels and tidal ranges (bottom) in southern Lombok waters, Indonesia from February 2000 to January 2001. \* Predictions of tide levels are referred to Chart datum 11 dms below MSL (mean sea level). 1 m = 10 dms.

for males and -0.677 for females), and GBI-tc were significantly correlated positively with air temperature ranges ( $r = 0.606$  for males and  $0.593$  for females).

Correlation analysis between the occurrence of each maturity stage (maturing, ripe, and partly spawned and spent) against the environmental factors revealed that the occurrence of each maturity stage in male *H. asinina* was not correlated ( $P > 0.05$ ) with environmental factors, except for maturing testes which were significantly correlated positively ( $P < 0.05$ ) with rainfall ( $r = 0.572$ ) and negatively with pH ( $r = -0.577$ ).

In females, maturing ovaries were significantly correlated positively ( $P < 0.05$ ) with maximum air temperatures ( $r = 0.659$ ) and days with rain ( $r = 0.590$ ) and negatively with sunshine-hours ( $r = -0.635$ ) and wind speed ( $r = -0.749$ ). Positive significant correlation ( $P < 0.05$ ) appeared between ripe ovaries and wind speed ( $r = 0.602$ ), and between ripe ovaries and tidal ranges ( $r = 0.693$ ), and negative significant correlation occurred between ripe ovaries and maximum air temperature ( $r = -0.622$ ) and between ripe ovaries and spring low tides ( $r = -0.724$ ).

## DISCUSSION

Studies on reproduction are usually time consuming, labour intensive, and expensive. Data should be collected on a regular basis, according to the cycle of environmental factors that may influence the reproductive strategy of the studied animals. Gonad indices (Poore, 1973; Shepherd and Law, 1974; Creese, 1980; Joll, 1980; Tutschulte and Connell, 1981; Hooker and Creese, 1995; Wilson and Schiel, 1995; Wood and Buxton, 1996; Ward and Davis, 2002) and oocyte size (Shepherd and Law, 1974; Wilson and Schiel, 1995; Wood and Buxton, 1996; Ward and Davis, 2002) are commonly measured in mollusc to assess annual reproductive cycles. Hahn (1989a) has reviewed the methods of gonad analysis that have been used to represent the reproductive cycle of haliotids, including gonad indices, gonad maturity stages and oocyte size

frequency. Gonad index is the simplest and most frequently used in haliotids. However, some bias on the use of gonad index has been encountered (Shepherd and Laws, 1974; Hahn 1989a).

In this study GBI-tc was used to present gonad development cycles for *H. asinina* due to its accuracy and sensitivity during the changes in gonad index, especially in the spawn, partly spawn, and spent animals. GBI-tc was calculated based on gonad volume, and slight changes in gonad area could have extreme effects on gonad volume. Gonad volume will increase significantly due to increases in oocyte size and sperm numbers at the end of maturation. However, it is reduced considerably after oocytes and sperm are released after spawning.

The used of GBI-tc was also applied in the study of Capinpin *et al.* (1998) for *H. asinina* in the Philippine waters. They found that the maximum value of GBI-tc in the male and female Philippine *H. asinina* was approximately 57 and 70, respectively. In the present study, however, the maximum value of GBI-tc was 122.5 in a male and 157.1 in a female. A possible explanation for this difference is that the size (SL and BW) of the animal collected in southern Lombok waters was larger than that in the Philippine waters. There was no information on body sizes of the abalone in Capinpin *et al.* (1998). Another possible reason is that the same sized abalone in southern Lombok waters has a larger gonad than that in the Philippine waters due to a better availability of natural food (quality and quantity) as well as the environmental condition (water quality). Southern Lombok waters is natural, no industrial activity around this area, and natural food for abalone are abundant including *Gracilaria* spp, *Hypnea* spp, *Acanthophora* spp, *Euclima* spp, *Laurencia* spp, *Sargassum* spp and *Ulva* spp (Atmadja and Subagdja, 1995).

On the basis of several criteria, this study revealed that *H. asinina* in southern Lombok waters breeds continuously. Short-term reproductive cycles were influenced by the lunar cycle (fortnightly), as histological analysis of gonadal stages revealed the presence of ripe, partly spawned and spent gonads in samples

collected at the new moon and full moon sampling. Over the longer term, the GBI-tc level of the population of *H. asinina* in southern Lombok waters significantly increased in the early eastern monsoon period (July) for both males and females. GBI-tc increased sharply during the eastern monsoon (August - September), when animals having ripe gonads were dominant in the population. A peak spawning event occurred at the end of the eastern monsoon (September - October), as the percentage of animals with ripe gonads dropped considerably in October. The GBI-tc then increased again in preparation for the second, lower peak spawning event occurring at the transition between the eastern and western monsoon (November - December), before animals returning to the regular spawning activity influenced by the lunar cycles (Fig. 3).

Further evidence that *H. asinina* spawns almost continuously is indicated by ripe, partly spawned and/or spent gonads occurring at almost any time of sampling, and this result is in agreement with the findings of Jarayabhand and Paphavasit (1996) in Thailand and Capinpin *et al* (1998) in the Philippines who found that *H. asinina* spawns almost continuously throughout the year. Spawning occurred mainly over a few (2 - 4) days around the new moon and full moon, however, outside of these times, individuals could spawn on any day.

Although *H. asinina* spawned continuously throughout the year, the peak of spawning occurred in September - March in Thailand (Jarayabhand and Paphavasit, 1996), which is longer than in the present study (August - November) for *H. asinina* in southern Lombok waters. Capinpin *et al* (1998) found that *H. asinina* were at a resting stage during the summer in the Philippines (May - June), but during these times *H. asinina* in southern Lombok waters were in an active stage, as the number of ripe gonads was high for the males and started to increase in the females (Fig. 5).

It is known that the reproductive cycles in marine gastropods are controlled by endogenous and exogenous factors. Kinne (1970) considered that besides endogenous factors, seasonal

variations in temperature, photoperiod and nutrition act as factors controlling the breeding cycle. Apart from acting as a stimulus for spawning, changes in temperature may also play an important role in gonad maturation, as well as in regulating reproductive cycles (Uki and Kikuchi, 1984; Hahn, 1989b; Wells and Keesing, 1989). For example, gonadal development of *Monodonta australis* coincided with an increase in sea temperatures (Lasiak, 1987), reproductive cycles of *H. iris* and *H. australis* appeared to track the changes in water temperature (Poore, 1973; Wilson and Schiel, 1995), and the period of maximum gonad growth of *H. laevigata* and *H. cyclobates* coincided with an abundant food supply and optimal feeding rates (Shepherd, 1973).

This study revealed that sea temperature was not the main variable regulating spawning in *H. asinina* in southern Lombok waters, as sea temperature was relatively constant throughout the year (Fig. 8). GBI-tc and the number of mature gonads (ripe and partly spawned) increased sharply in July - September (Fig. 3), coincident with the increase in sunshine-hours (Fig. 7). The increase in gonad index coincident with sunshine-hours was not very convincing, but statistical analysis showed that gonad maturation was correlated with increases in sunshine-hours (light intensity) and exposure to high air temperatures during spring low tides that occur during the day and to low air temperatures during spring low tides occurring at night. Underwood (1974) suggested that sea and air temperature possibly act as stimuli for initiation and cessation of phases of the reproductive cycles in the prosobranchs (*Nodilittorina pyramidalis*, *Littorina unifaciata*, *Bembicium nanum*, *Morula marginalba*, *Cellana tramoserica* and *Montfortula rugosa*). It was found that GBI-tc values of both male and female *H. asinina* in southern Lombok waters were significantly correlated with minimum air temperature and air temperature ranges.

This study supports the statement of Counihan *et al.* (2001) that *H. asinina* can detect changes in tidal profile, and requires exposure to hot air

temperatures during the day and cooler air temperatures during the night, to induce the physiological changes and behaviour associated with spawning. Although the gonad index (GBI-*tc*) was not correlated directly with tide levels and tidal ranges, these factors influence the degree to which *H. asinina* in coastal areas is exposed to the air. It was found that spring low tide was negatively correlated with the frequency of animals with ripe ovaries, while tidal ranges were positively correlated with the frequency of animals with ripe ovaries.

The higher wind speeds due to the eastern monsoon in Lombok that caused sea condition on coastal areas to be taken into account as a variable that influences gonad maturation. Some studies have shown that vigorous water movement and storms are a spawning stimulus. For example this is known for littoral prosobranchs, *Melarapha cincta* and *M. oliveri* (Pilkington, 1971), the limpet, *Notoacmea petterdi* (Creese, 1980), the New Zealand trochids, *Melagraphia aethiops* and *Zediloma atrovirens* and the turbinid, *Lunella smaragda* (Grange, 1976), and the Japanese abalone, *H. discus hannai* (Sasaki and Shepherd, 1995). It was also found in the present study that the occurrence of ripe ovaries correlated positively with wind speed.

Major spawning period of *H. asinina* in southern Lombok waters started in August after sunshine-hours was maximum, no days with rain, wind speed started to slowdown and the sea became calm (Fig. 7 and 8). This major spawning period continued through November when the sea condition was relatively calm. This event is in agreement with the finding of Singhagraiwan and Doi (1992) in Thailand and of Counihan *et al.* (2001) in Heron Reef, Australia, who noted that spawning of *H. asinina* was associated with an increase in water temperature when the sea was calm. It is understood that increases in temperature act as a trigger or stimulus for spawning (Shepherd and Laws, 1974; Uki and Kikuchi, 1984; Hahn, 1989b) and that spawning of haliotids mostly occurs in calm conditions (Breen and Adkins, 1981)

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