

## A Preliminary Study: Marine Biogeography of *Nautilus* in the Bangka Belitung Seas, Indonesia

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### Abstract

*Nautilus* is the only surviving genus whose members were numerous and widely dispersed in the oceans throughout the Jurassic and Miocene times. It represents the only living member from the Family Nautilidae and is often considered as a living fossil. *Nautilus* is found with high biodiversity in Ambon, Indonesia, and were in special cases even found in Bangka Belitung, far from their original habitat. This study aimed to understand the historical component of the habitat and distribution of *Nautilus* in Bangka Belitung and to determine the depth, temperature, current, and environmental heterogeneity relate to *Nautilus*. *Nautilus* samples were found in Bangka Belitung Seas nearby a crack region at 50–75 m deep while the optimal depth of the *Nautilus* was 150–300 m, depending on the local area. The locations in the Bangka Belitung Seas where *Nautilus* found have sea surface temperatures between 30-31°C and 27-28°C during the East Monsoon and the West Monsoon respectively. The implications of temperature as a limiting factor are fairly significant, as it restricts the upper limit of the living habitat to predictable depths, which vary both geographically and seasonally during the West Monsoon when surface temperatures approach habitable levels. Sea currents at the Bangka Belitung Seas move at 0–0.6 m.s<sup>-1</sup> during the East Monsoon and speed up near the North Natuna Sea. During the West Monsoon, currents predominantly flow from the Natuna Sea to the Java Sea at 0–0.5 m.s<sup>-1</sup>. Large-scale deep-water currents and the effects of smaller currents on scent dispersal influence the directional movements of *Nautilus*.

**Keywords:** *nautilus*, marine biogeography, Bangka Belitung, living fossil, environmental

### Introduction

The genus *Nautilus* is known to be represented by at least six extant species that inhabit a well circumscribed large area in the Southwestern Pacific Ocean, The Philippines, Indonesia and Australia. Having survived relatively unchanged for hundreds of millions of years, *Nautilus* represents the only living members of Family Nautilidae and are often considered as *living fossils* (Saunders and Landman, 2010). The Quaternary period represents the most recent moments of Earth's history and despite its current relatively brief duration, knowledge of its faunas is highly important as they are close ancestors of modern ones. When some of the main concerns about animal life are diversity, biological invasions, and range modifications caused by global change, an analysis of the near past can show diverse geological and biological clues for understanding and managing

present ecosystems (Martinez *et al.*, 2003). The genus *Nautilus* is known to be represented by at least six extant species that inhabit in a well-circumscribed extensive area in the southwestern Pacific Ocean, the Philippines, Indonesia, and the tropical seas of Australia (Saunders and Landman, 2010).

Miller (1949) was the first to recognize that the evolution of Nautilida surged ahead in the Late Cretaceous and Early Tertiary periods and across the Cretaceous-Tertiary boundary, at which time the Ammonoidea became extinct. However, it is by no means close to natural extinction. On the contrary, *Nautilus* is a viable genus on the threshold of a new period of evolutionary radiation that, given favorable climatic and other environmental conditions, may unfold during the next few million years. The first specialist to publish an article on a Nautilida fossil included *Nautilus* was Shimansky (1957) whose studied

*Nautilus praepompilius* from the Eocene period of Russia. Squires (1988) described Eocene specimens and placed them in the Family Nautilida. Saunders et al. (1989) followed Shimansky (1957) and went into further detail on similar fossils.

Biogeography is the study of the distribution of organisms and of principles that govern it. This discipline plays a critical role in understanding marine biota evolution and adaptation. The field of biogeography is rich in studies of small groups of better-known species at local to regional scales (Briggs and Bowen, 2012), but has relatively few examples of generalized studies (Kreft and Jetz, 2010). There are three models in biogeography for studying origins within marine biodiversity of Pacific and Indian Ocean faunas, namely the 1) center of origin, 2) center of accumulation, and 3) center of overlap. The center of origin model is the most supported, premising a flow of species from high-diversity centers enhancing species abundance in outlying communities (Briggs and Bowen, 2013). Previous research has shown that some migration may take place inward and toward the diversity center (Saunders and Landman, 2010). Marine biogeography is necessary for the planning of conservation strategies and management interventions, especially for Nautilidae.

Marine biogeography of *Nautilus* is highly complex and explaining the distribution patterns may require the synthesis of current ecological and biogeographical theories. One area where *Nautilus* has been found is Ambon, Indonesia. *Nautilus* inhabit deep continental shelves with the optimal range seeming to be 150-300 m. The worldwide biogeographic distribution of *Nautilus* is restricted to the Indo-Pacific region on steep coral reef drop-offs and at depths of 0-700 m (Dunstan and Ward, 2010). In an unexpected occurrence, *Nautilus* was found in Bangka Belitung, far from their original habitat, where the maximum water depth is 50-75 m. This study aimed to clarify the historical component of the habitat and distribution of *Nautilus* in Bangka Belitung and to determine how depth, temperature, currents, and environmental heterogeneity relate to *Nautilus*.

## Materials and Methods

### Data collections

The samples were collected by local fisherman around 2018 - 2020 which catching at the Nasik Strait and Selu Island, Belitung Regency, Bangka Belitung Islands, Indonesia. Purposive sampling was done at the locations where drifting *Nautilus* shells were sighted.

### Bathymetry data

Bathymetry which describes the depth profile of the ocean has been use for predict the habitat of *Nautilus*. Bathymetry data based on the General Bathymetry Chart of the Ocean (GEBCO) and obtained from the GEBCO website at <https://download.gebco.net/>. The resolution was set to 15".

### Currents and sea surface temperatures

To analyze the relation between *Nautilus* distribution and oceanographic conditions, the currents and sea surface temperature (SST) profile of the study area was studied. The currents and SST profile were obtained from the InaROMS RCP45 model made by the Indonesian Geospatial Information Agency and is accessible at <http://tides.big.go.id:8080/las/UI.vm>. The profile comprises a reanalysis of model results and field data, specifically from the territorial waters of Indonesia at a 5 km resolution. The East Monsoon period between July 1-31, 2019 and the West Monsoon period between January 1-31, 2020 of the currents and SST profile were investigated.

## Result and Discussion

### Center of origin and dispersal

Nautiluses are primarily mobile benthic bottom dwellers associated with coral reefs. They are found at depths ranging from the surface until 500 m, but their optimal range seems to be from 150-300 m (Jereb and Roper, 2005). Previous studies investigated Nautilida both in the wild and in captivity from a wide range of populations, including from the Philippines, Palau, Indonesia, Papua New Guinea, Fiji, and Australia, to provide data on distribution, habitat, growth, time to maturity, and lifespan (Collins and Ward, 2010; Landman and Cochran, 2010). (a) *Nautilus macromphalus*, Sowerby (1849) inhabits continental shelves and slope waters associated with coral reefs, ranging from the surface to roughly 500 m deep. They are currently only known to be found in northeastern Australia and the Loyalty Islands province in New Caledonia. Drift shells have been recorded as far south as Lizard Island, Queensland, Australia (Jereb and Roper, 2005). (b) *Nautilus pompilius* Linnaeus (1758) is the most widely distributed and best-known *Nautilus* species. It inhabits deeper continental shelves around coral reefs and found at surface levels down to 750 m deep. They are geographically distributed around the Indo-West Pacific, ranging from the Andaman Islands to Ambon in Indonesia, the Philippines, New Guinea, and Fiji, and northeastern and northwestern Australia (Jereb and Roper, 2005). (c) *Nautilus belauensis*, Saunders (1981): This species of *Nautilus* was

named for their characteristically large forms and are found in Palau (Belau) and the western Caroline Islands (Saunders, 1981a). *Nautilus belauensis* is known only from its typical locality, Palau, although there have been no attempts to establish whether its range extends to any of the adjacent Caroline Islands. Some *N. belauensis* specimens were caught at depths of 100–400 m (Saunders and Landman, 2010). (d) *Nautilus repertus*, Iredale (1944): The specimens described by Iredale (1944) were found off the western coast of Australia at Pelsaert Island, Houtman Abrolhos, and Rottneest Island. A specimen with soft parts was found in Foul Bay in South Australia, directly off the coast of Yorke Peninsula (Riddle, 1920). Most recently, 14 shells of live-caught specimens were obtained by deep-water shrimp bottom-trawls, operating approximately 200 km off Broome, Western Australia, at a depth of 380–450 m (Saunders and Landman, 2010). (e) *Nautilus stenomphalus*, Sowerby (1849): *Nautilus stenomphalus* has only been found in the Great Barrier Reef, Queensland, Australia, whence most drift shells ascribed to this species are also derived, suggesting that its range may be limited to that region (Saunders and Landman, 2010). (f) *Allonautilus*

*scrobiculatus*, Lightfoot (1786): *Allonautilus scrobiculatus* is found in the tropical West Pacific, specifically in the Bismarck Archipelago and Milne Bay of Manus, Papua New Guinea. Drift shells have been found as far south as the Solomon Islands. (g) *Allonautilus perforatus*, Conrad (1847): *Allonautilus perforatus* has only been found in Bali, Indonesia.

Surprisingly, some *Nautilus* were found in Bangka Belitung (Figure 1.), far from genus *Nautilus*' known habitats. Several *Nautilus* samples from Bangka Belitung were found near a crack which is characterized by an area deeper than is surrounding (>50 m) (Figure 2.).

#### Oceanographic conditions of Bangka Belitung

Oceanographic conditions are an important supporting aspect of the *Nautilus* distribution analysis, especially for the interconnectivity of *Nautilus* from different regions. Other aspects are bathymetry, currents, and sea surface temperatures. In Bangka Belitung itself, the ocean floor is fairly shallow at around 0–75 m due to Bangka Belitung being on the Asian continental plate, similar to



**Figure 1.** Data collection of *Nautilus* from Bangka Belitung. (length of sample: Babel-001: 11.4 cm; Babel-002: 12.2 cm; Babel-003: 8.7 cm; Babel-004: 12 cm; Babel-005: 11.8 cm)

Singapore's, Malaysia's, and Thailand's shallow waters. At Gaspar Strait, situated between Bangka Island and Belitung Island (Figure 2.), there is a narrow crack extending from the south (Sunda Strait) to northwest (Singapore, Melaka Strait, Thailand) (Figure 2.) which is deeper than its surrounding and reaches 75 m.

Five nautiluses were found at Bangka Belitung near the crack region (Figure 2.), but not in other locations. This showed that the Nautilus habitat in Bangka Belitung waters was primarily in the narrow-deep crack. According to Jereb and Roper (2005) and Saunders and Landman (2010), the optimal depth of *Nautilus* habitats is around 150–300 m and no deeper than 800 m, determined by shell implosion and chamber flooding. Factors controlling the habitat's upper limits include predators and temperature. Temperatures exceeding 25°C may be lethal to Nautilus. However, this limitation does not prevent them from moving into warm, shallow water for brief periods as *N. business* has been found in water approaching 28°C, but such incursions are probably of short duration (<10 h).

Western Indonesia (including the Bangka Belitung Seas) is strongly influenced by monsoon

winds. The monsoons comprise two phases, namely the East Monsoon in June, July, and August (JJA) and the West Monsoon in December, January, and February (DJF) (Wei et al., 2016). The Sea Surface Temperature (SST) analysis of the Bangka Belitung Seas shows that this study's nautiluses were found where surface temperatures range between 30-31°C during the East Monsoon and between 27-28°C during the West Monsoon. Optimal temperatures for *Nautilus* at <100 m deep range from 23-25°C and 15-18°C at 150–180 m deep (Saunders and Landman, 2010). Their minimum water depth is constrained by water temperatures above 28°C. As most shallow waters across the range of the *Nautilus* habitat are warmer than this, these high surface water temperatures and visual predators make dispersal in surface and near-surface waters rare (Carlson, 2010; Williams et al., 2012). The implications of temperature as a limiting factor are fairly significant. It restricts the upper limit of habitats and long-term migration to predictable depths, which vary both geographically and seasonally. Thus, extensive movement across shallow-water platforms, such as the Palau Archipelago, is not possible, but shallow-water occurrences of *Nautilus*, as reported in New Caledonia and the Loyalty Islands, may be common during the winter months, when

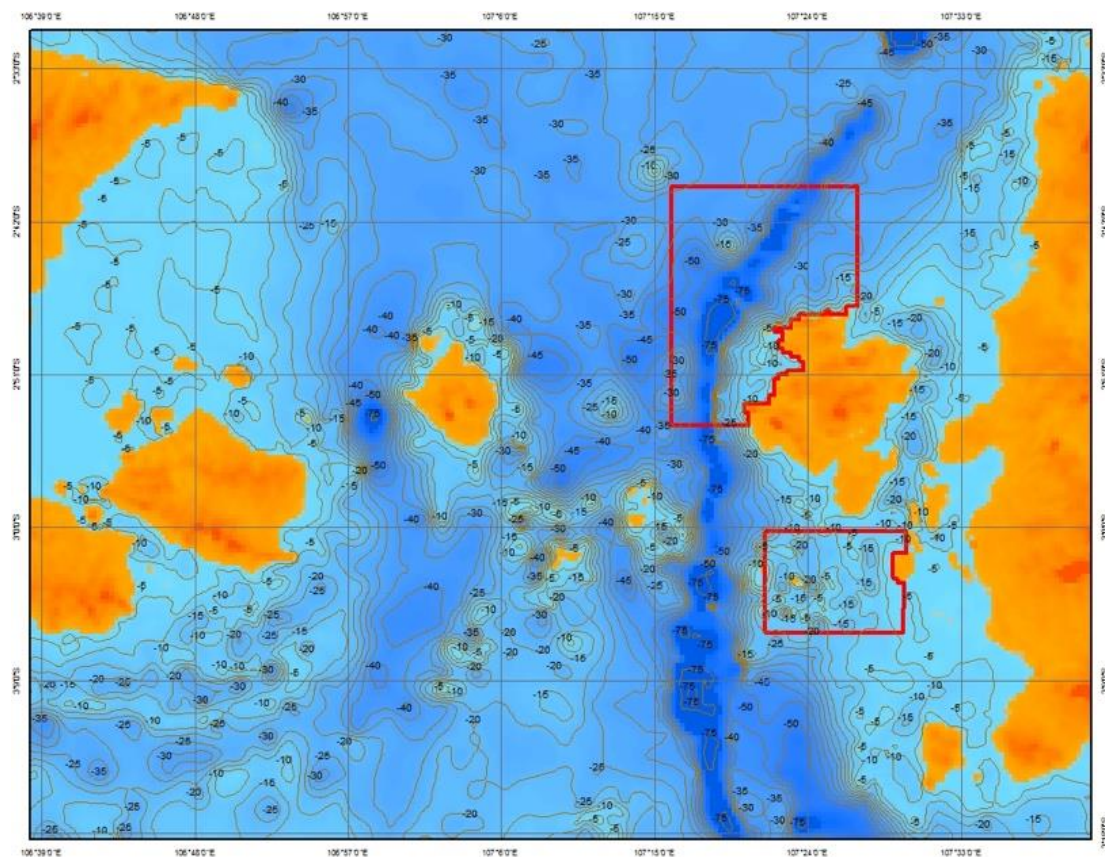


Figure 2. Bathymetry and spatial distribution of *Nautilus* in Bangka Belitung (Source: GEBCO <https://download.gebco.net/> and field sampling data). The red boxes show the areas were *Nautilus* found

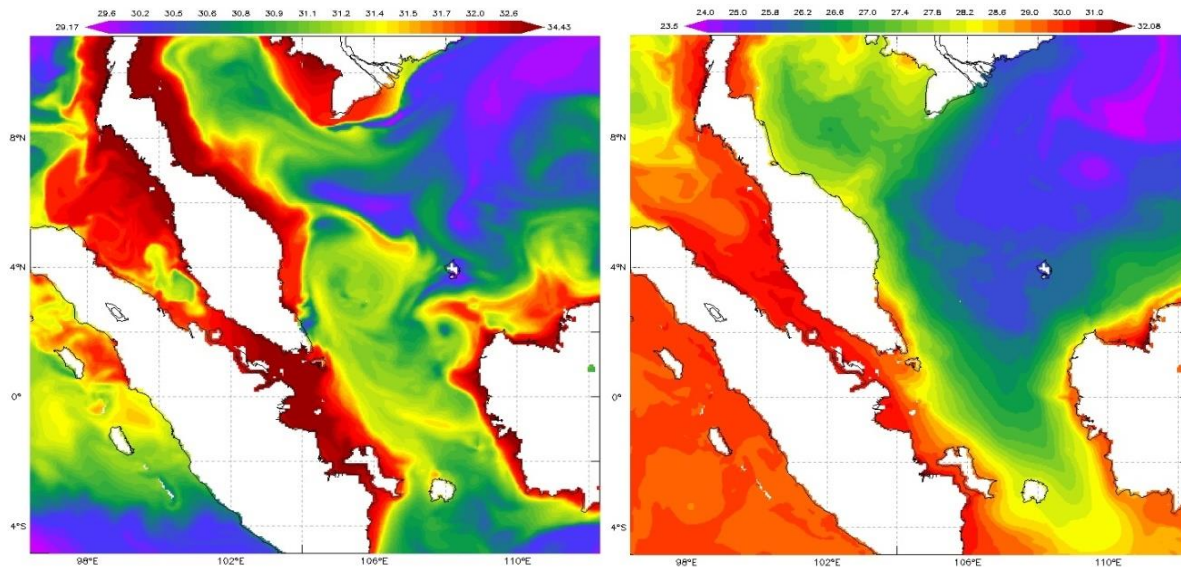


surface temperatures approach habitable levels (Ward and Martin, 1980). Unclear is why *Nautilus* occurrences are not more common in regions where optimal temperatures are consistently encountered at shallower depths. This may be related to biological factors, as mentioned by Ward *et al.* (2016), *Nautilus* habitats are normally close to rich sources of tropical vegetation that bring copious amounts of carbon into the fore-reef slope muds, making these areas rich in nutrients and life.

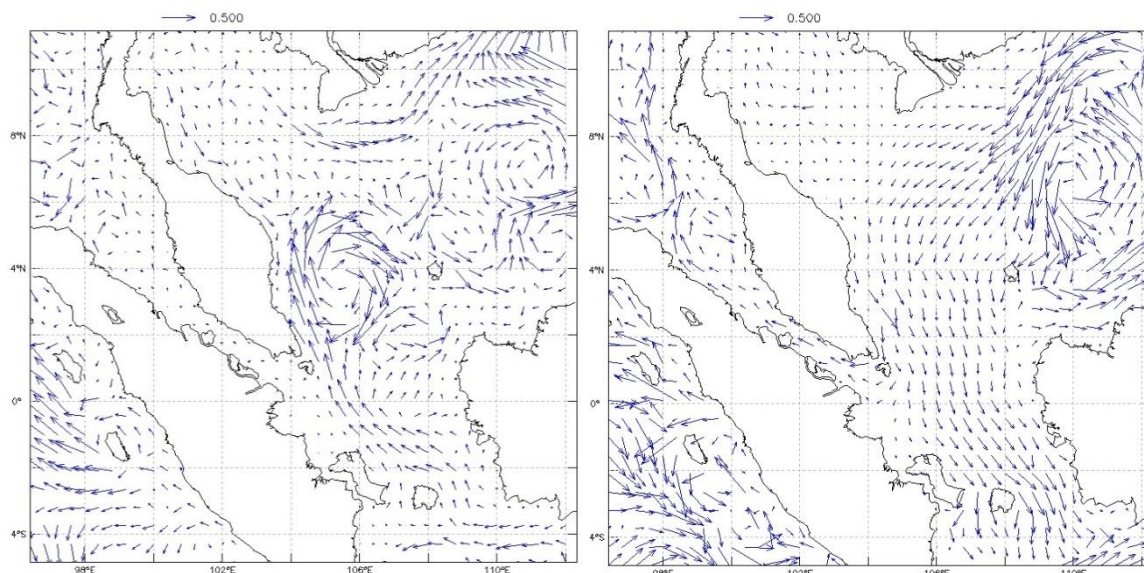
*Nautilus* is irregular and unpredictable in their area of occupancy and their distribution in areas where they are known to occur is patchy. Nautiluses

have physiological constraints that limit their vertical and horizontal distribution to geographically-separated areas of suitable habitat (Barord *et al.*, 2014). In areas where water temperatures drop seasonally, chambered nautiluses will range into much shallower water nocturnally.

Winds blow from Asia to Australia during the East Monsoon, and vice versa during the West Monsoon. These winds greatly influence the current patterns of the Bangka Belitung Seas (Pamungkas, 2018) because geographically the Bangka Belitung Seas are between two oceans (Natuna and Java Seas) and between two large islands (Sumatera and



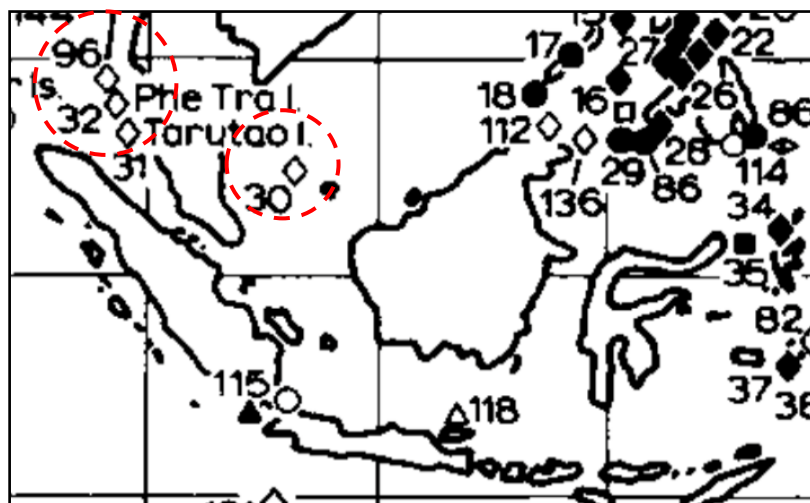
**Figure 3.** Sea Surface Temperatures (SST) of Bangka Belitung and surroundings during the East Monsoon (left) and the West Monsoon (right) (Source: Ina ROMS rcp45, <http://tides.big.go.id:8080/las/UI.vm>).



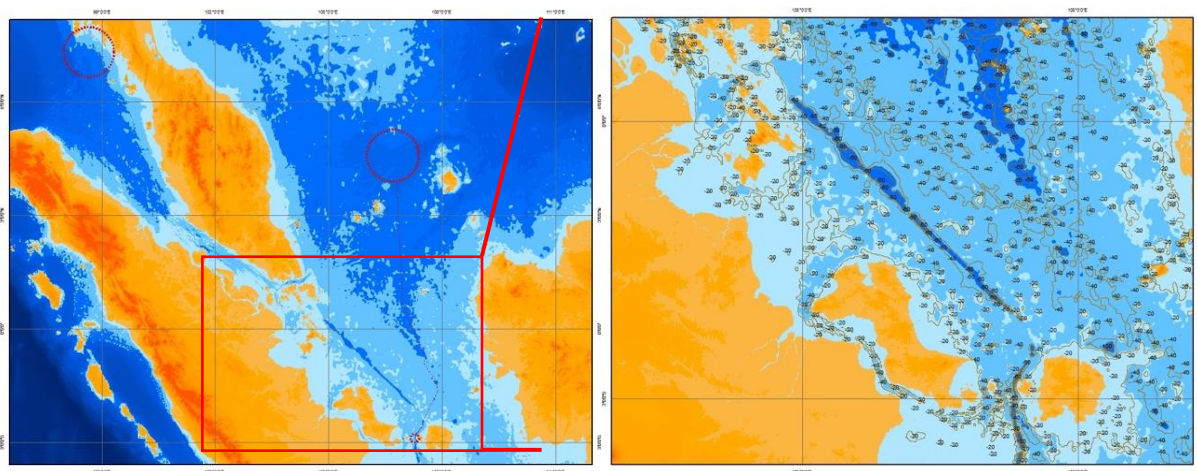
**Figure 4.** A current profile of the Bangka Belitung Seas and surroundings during the East Monsoon (left) and the West Monsoon (right) (Source: Ina ROMS rcp45, <http://tides.big.go.id:8080/las/UI.vm>).

Kalimantan Islands) (Ambalika *et al.*, 2019). Currents during the East Monsoon follow the direction of the wind and predominantly flow from the south (the Java Seas) to the north (the Natuna Sea) (Figure 4.). During the East Monsoon, current speeds are around 0–0.6 m.s<sup>-1</sup> and are amplified as they approach the North Natuna Sea (Eastern Malaysia). During the West Monsoon, as the winds blow from north to south, currents flow from the Natuna Sea to the Java Sea (Figure 4) at 0–0.5 m.s<sup>-1</sup>. Currents tend to move faster in the South China Sea and slow down as they approach the Bangka Belitung Seas. Another current flows through the Malaka Strait during both the East and West Monsoon connects the Bangka Belitung Seas with the West Thailand Sea. The directions of movement of *Nautilus* may be influenced by large-scale deep-water currents, they may be related to the effects of smaller currents on scent dispersal, or they may be random (Saunders and Landman, 2010).

The *Nautilus* found in the Bangka Belitung Seas around the crack region (Figure 2) is expected to be related to *Nautilus* from the Thailand Sea (Figure 5.) because the crack with a depth of up to 75 m, where drifted shells of *Nautilus* were found, connects both seas (Figure 6.). The *Nautilus* drift shells found in the Thailand Seas are from the same species as those found in the Bangka Belitung Seas, namely *Nautilus pompilius* (Saunders and Landman, 2010). Ward *et al.* (2016) explained that the *Nautilus* habitat is partly characterized by deep sloping sandy bottoms with little to no structure, and partly by sharp, steep reef slopes with varying depth changes. *Nautilus* depth movement was more gradual and consistent on sandy sea beds and more varied when migrating through rocky sea beds and reef walls. Therefore, the environmental structure of *Nautilus* habitats may be useful for determining how nautilus migrate.



**Figure 5.** Recorded distribution of living *Nautilus* (black points) and *Nautilus* drift shells (white point) (Adaptation: Saunders and Landman, 2010). The striped red circles are recorded locations of *Nautilus* in the Thailand Sea.



**Figure 6.** Bathymetry map of the Bangka Belitung Seas and the West Thailand Sea (Source: GEBCO <https://download.gebco.net/>).

The depth, currents, and SST analyses correlate with the discovery of *Nautilus* in the Bangka Belitung Seas. This becomes an important role to preserve *Nautilus* because all species are vulnerable to exploitation based both on intrinsic biological traits, including their limited biogeographic distribution and selected life history strategy, and extrinsic threats of being targeted, a largely unregulated harvest, and mortality or habitat degradation caused by other human activities such as destructive fishing practices and overfishing.

## Conclusions

*Nautilus* shells were found in the crack region in the Bangka Belitung Seas at 50–70 m deep. The SST where *Nautilus* was found ranges between 30–31°C during the East Monsoon and between 27–28°C during the West Monsoon. The speed of currents in the Bangka Belitung Seas during the West Monsoon is 0–0.6 m.s<sup>-1</sup> and is amplified near the North Natuna Sea. During the West Monsoon, currents of the Bangka Belitung Seas predominantly flow southward from the Natuna Sea to the Java Sea with speeds of 0–0.5 m.s<sup>-1</sup>. The directional movements of *Nautilus* may be influenced by large-scale deep-water currents and the effects of smaller currents on scent dispersal. Because of its difference from other *Nautilus* habitats, it can be argued that the appearance of *Nautilus* in the Bangka Belitung Seas is somewhat of a rarity, despite the Bangka Belitung Seas being quite representative of *Nautilus*' habitats. In unscientific terms, nautilus are rare.

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