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Banda deep-sea research: history, mission and strategic plan

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Abstract. Attention to the deep-sea ecosystem research in order to achieve blue economy goals is low. The Banda Sea is important deep-sea ecosystem in Indonesia and it was identified as a global marine mega-biodiversity site. The objectives of this paper are 1) to document the history, achievements, and challenges of deep-sea research development and 2) to develop a grand design and innovative strategic plan for deep-sea research. Literature reviews and questionnaire survey for scientists across Indonesia were carried out. The literature reviews indicated that deep-sea ecosystem is not well documented. Few articles on deep-sea were published (mean 0.8 article y^{-1}) which were mainly focused on geological (45%) and physical oceanography (32%), less research on biological (16%) and chemical oceanography (8%). Deep-sea ecosystem faced tremendous threats due to ecosystem degradation, pollution, and climate change. The questionnaire survey showed that research infrastructure/facilities (Ranking 1) and institutional management systems (Ranking 2) were the main obstacles to Indonesian deep-sea research development. A grand design named Indonesian Deep-sea Research and Monitoring (I-DREAM) and its strategic plan were developed to achieve blue economy goals. Strengthening research infrastructure and institutional management systems are the top priorities that should be achieved in the short-term period to support deep-sea research in Indonesia. Scientific pursuit in long-term period should be focused on biodiversity and deep-sea ecology including chemical oceanography (24%) and its interaction with other ecosystems and atmosphere (18%) were identified as the top priorities to be implemented for future research (Ranking 1 and 2). The Banda Sea was identified as a suitable core study area of the I-DREAM's pilot project. The grand-design and its innovative strategic plan are essential to fulfilling high demand on a guideline for deep-sea research to achieve blue economic development goals.

Keywords: Deep-sea, blue economy, grand design, strategic plan, Banda Sea, marine research

1. Introduction

Around 75% of Indonesian territory is sea and most of Indonesia seas have deep-sea zones (below 200 m) [1]. Located in the tropical region, making the Indonesian seas biologically rich resources and rich of energy resource such as oil, gas, and minerals [1,2]. The Banda Sea (± 0.54 million km^2) is the largest deep-sea in Indonesia located in Maluku Province [3]. In addition, the Banda Sea is known as one of the deepest seas (7440 m) in the world [4,5].



The Banda Sea is a marine mega-biodiversity centre situated in the Coral Reef Triangle Initiative area. Marine biota and various ecosystems such as mangroves, seagrass, and coral reef are found in this seascape [6, 7]. In 2009, the ministry of Marine Affairs and Fisheries (Ministerial Decree No. 60 2009 and No. 58 2014) declared the Banda Sea as a national marine protected area of 25 km² [8]. It is including Banda Islands, located in the middle of the Banda Sea (Figure 1).

It is predicted that human population in Indonesia will grow up to 300 million in 2035 [9] and Indonesia will face both biological and natural resources crisis especially food and energy [10-12]. Deep-sea ecosystems provide ecological functions and ecosystem services and rich of biological resources [13-15]. These potential of deep-sea are important to achieve blue economy goals especially to support food and energy security and marine infrastructure [14]. For example, marine biota could be used as a raw material of medicine and food. Deep-sea potentially have alternative energy resources and important for infrastructure development (e.g. communication network, tunnel, etc.).

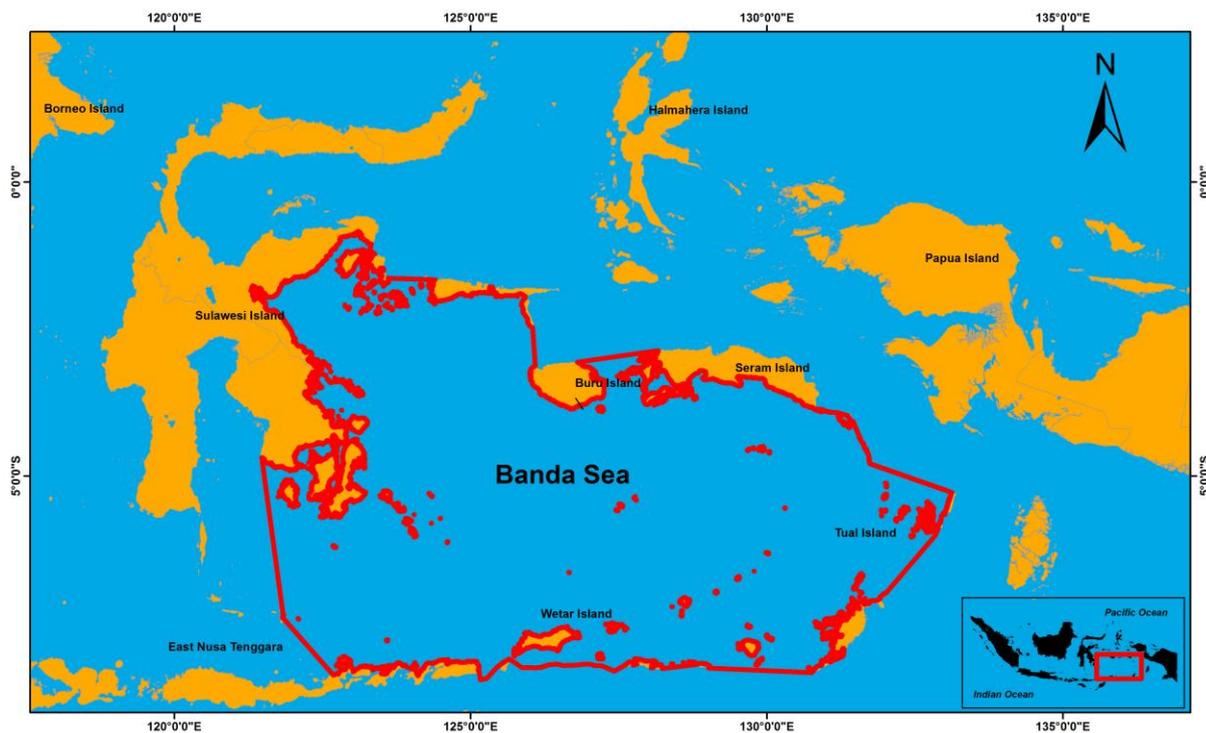


Figure 1. The Banda Sea is located in the eastern part of Indonesia.

The blue economy is a concept of sustainable use of sea resources for economic growth, improved livelihoods and jobs, and sea ecosystem health [16]. The blue economy goals include six main aspects: tourism, renewable energy (i.e., OTEC/Ocean Thermal Energy Conversion, which is a process that can generate electricity by using the temperature difference between deep cold ocean water and warm surface of the Banda Sea water), climate change, fisheries, maritime transport and infrastructure, waste management and conservation [16]. This concept includes deep-sea, small islands, coastal areas, and shallow sea. However, the deep-sea resources and its ecosystem conditions are not well explored. Deep-sea ecosystems face tremendous threats due to human activities and environmental change, such as environmental degradation, climate change, and water pollution [17-19]. In addition, scientific information on the interconnectivity of deep-sea, coastal, and terrestrial ecosystem is lacking.

Deep-sea research and monitoring are highly required to achieve the blue economy goals especially to mitigate the biological and natural resources crisis and to ensure sustainable use of the resources through conservation actions. However, grand-design and strategic plan of deep-sea research are not

available yet. These documents are required to ensure that deep-sea research activities are effective to achieve the blue economic goals. This study is the first effort to review Indonesian deep-sea research and to develop a grand design for future deep-sea research. The objectives of this study were: (1) to document the history, achievement, and challenge of deep-sea research in Indonesia including in the Banda Sea; and (2) to develop a grand-design and strategic plan of deep-sea research to achieve blue economy goals. Literature review and questionnaire survey were conducted to address the described objectives.

2. Methodology

Two main methods were applied: literature review and questionnaire survey (Figure 2). A literature search was conducted to identify published literature containing information on deep-sea research in Indonesia from the last three centuries (1872-2017). Challenger expedition (1872) was used as starting point of literature review because this expedition was known as the first milestone for oceanography studies in Indonesia [20]. Relevant peer-reviewed studies within Scopus, ISI Web of Science (Thomson Reuters), and Google Scholars were searched using keywords combination such as “deep-sea” AND “Indonesia” or “deep-sea” AND “Banda Sea”. Only original research paper published in international, national and local journals/proceedings and graduate thesis were included in the study. Hand-searching was conducted in Indonesian Institute of Sciences (LIPI) libraries for articles which were not published online. Secondly, articles obtained were filtered manually to check for their relevance to the deep-sea research. Lastly, the obtained articles were categorized according to four main subjects: geological oceanography, physical oceanography, chemical oceanography, and biological oceanography.

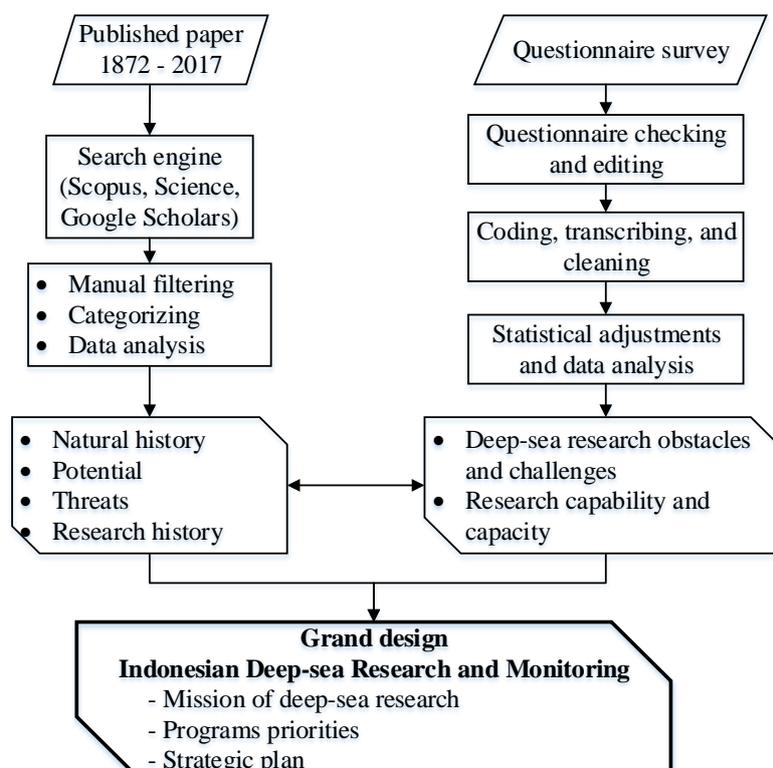


Figure 2. Flowchart of methods: literature review and questionnaire survey used in the study.

A questionnaire survey was conducted in August – October 2017 for 28 respondents in total. The respondents were scientists/researchers (75%) and lecturers (25%) across Indonesia with master and doctoral degree and minimum research experience of eight years. The demography of the respondents was: ages = 29 – 60 years, male = 74%, and female = 26%. There were two types of questions: open-ended questions and close-ended questions (response-option questions). The responses of the questions were designed as single responses, multiple responses, ranked responses and rated responses. There were three main steps in data processing (figure 1): (1) questionnaire checking and editing to eliminate unacceptable questionnaires and to correct inconsistent and ambiguous answers; (2) coding to assign alpha or numeric codes, transcribing, and cleaning for consistencies; (3) statistical adjustment and data analysis. Statistical adjustment is required to data that requires weighting and scale transformations. The data were analyzed using descriptive analysis in SPSS version 22 (IBM, New York, USA) and the data were normalized using z-score to vary between 0 and 1, thus allowing a comparison and a rank over the different calculated analytical values [21].

3. Result and discussion

3.1. Natural history of the Banda Sea

Located in eastern Indonesia (3.47°S – 7.65°S and 122.42°E – 131.47°E), the Banda Sea (± 0.54 million km²) is important waters surrounded by small islands of Southeast Sulawesi, Ceram, Wetar, Timor and Tanimbar islands [3]. The Banda Sea consists of six basins within ranges from 2000 m to 7440 m. It has the greatest active arc and active volcanos in Indonesia, making the seascape and islands geologically dynamics [22, 23]. The maximum depth 7440 m was located in the Weber Basin [24]. The depth of the Banda Sea was classified into three zones: bathypelagic (200 - 1000 m), abyssopelagic (1000 - 4000 m), and hadalpelagic zone (>4000 m) [25].

The sea was subjected to two winds: northwest monsoon (from the west, November to March) and southeast monsoons (from the east, May to September) with transitional months on October and April [3, 26]. These monsoons influence the movement of water mass (upwelling and down-welling) and water circulation [27-29]. Upwelling happened on the southeast monsoon and downwelling occurred on the northwest monsoon [3, 30]. Water temperature and salinity in the bathypelagic zone were described as Antarctic Intermediate Water which flows from north to western Pacific. The characteristics of water in the abyssopelagic were not influenced by Antarctic Bottom Water [25]. Water temperature in the abyssopelagic was higher (4.8–5.25 °C) compare to the international standard of abyssopelagic temperature [31].

The Banda Islands, which is situated in the middle of the Banda Sea, consist of inner islands (Banda Naira, Banda Besar, Pisang Island, Karaka Island, and Gunung Api Island) are mountainous and forested islands, with volcanic soils. The outer islands (Hatta Island, Ay Island, Nailakka Island, Rhun Island, and Manukan Island) are uplifted limestone and they are flatter and dryer than the inner islands [32]. Traditionally, local people on the islands have local wisdom called “sasi” to conserve marine resources [34, 35]. However, this local wisdom is under pressure and almost disappeared due to modernization [35].

3.2. Potential of the Banda Sea for blue economy development

The Banda Sea is identified as an important site to support the blue economy development and blue carbon through biodiversity, tourism and transportation, and deep-sea mining as discussed in detail below [36, 37].

Biodiversity centre: the Banda Sea and adjacent waters are habitats for many marine biotas including 133 species of mangroves, 91 species of mollusc, and many species of fish. Maluku including the Banda Sea is the habitat for 128,000 ha of mangrove forest [6]. The Banda Sea contributes about 4.3% of the national fisheries such as tuna and pelagic fish [38]. This area was declared by the Indonesian Government (Kepmen No. 714) as the main fishing ground for pelagic fish and tuna. The other important marine resources are shrimps, lobsters, coral, and demersal fish [39]. In

addition, the eleven small islands in the Banda Sea were the world's sole source of nutmeg made the Banda Islands called as the "Spice Islands" [32, 33].

Tourism and transportation: the Banda Sea and the islands are popular tourist destinations for scuba diving, marine conservation, historical heritage, and traditional culture [40]. It was not clear how many local and international tourists visiting the Banda Sea and the islands. However, the Banda Neira Airport tourist information service estimated of 600-1,500 foreign tourists visited the Banda Sea and the islands during 1990-1994. The Banda Sea is an important marine transportation network linked eastern Indonesia (e.g. Ambon, Tual, and Papua) and western Indonesia (Sulawesi, Java, and West Nusa Tenggara, etc.) [41]. In addition, the Banda Sea is a "bridge" connecting northern and southern part of the Maluku Province [42].

Mining: the Banda Sea has good potential for oil, gas, and mineral resources, but it is not explored well [43]. Regardless of the controversy of the mining system inshore or offshore, the exploration provides a new perspective about the deep-sea mining for energy supply to local society. For example, the development Liquid Natural Gas (LNG) mining of Masela Block located in two small islands was started in early 2000 [43].

3.3. Threats of Banda Sea

Generally, the threats of the Banda Sea can be categorized as anthropogenic and natural threats. Environmental degradation (e.g. mangrove deforestation and pollution) and overexploitation (e.g. overfishing, coral-reef exploitation) are main anthropogenic threats. For example, mangrove forest area in Maluku including the Banda Sea decreased from 198,000 ha in 1980 to 100,000 ha in 2005 [6]. Recently, mangrove area in the Ambon Bay, part of the Banda Sea, was decreased by 10.53% at the rate of $1.5\% \text{ y}^{-1}$ due to coastal area development [44]. Overfishing is a new threat since the increasing of purse seine fisheries operated in the Banda Sea.

The impacts of climate change such as sea level rise and unpredictable weather (heavy rain, storm, and high tide) were tremendous threats to the deep-sea ecosystem [45]. An unprecedented threat such as mortality of large marine mammals was recorded in the Banda Sea due to climate change associated with changing in the monsoons [14, 19, 46]. Household waste and pollution were other anthropogenic threats. Around 60% of Indonesian plastic waste dumped into the sea. [47]. Illegal activities of gold mining in the Buru Island, for example, polluted the waters and marine ecosystem.

The Banda Sea is located in the ring of fire where a large number of earthquakes, volcanic eruptions, and tsunamis were recorded. This is due to the Banda Sea was created as a basin and active subduction zone of Sunda tectonic plate and Sahul tectonic plate. The Indonesian Agency for Meteorology, Climatology, and Geophysics recorded 1,222 earthquake events occurred in Maluku in 2016. This natural disaster might cause environmental degradation of the deep-sea ecosystem.

3.4. Research history in the Banda Sea

The literature review showed that deep-sea research activities in the Banda Sea have been started since the 19th century when the Challenger expedition (1872-1876) took place in the Banda Sea [20]. Afterward, several international and local expeditions were undertaken in the Banda Sea including Galathea expedition (1950-1952), SEATAR (Studies on South East Asia Tectonics and Resources) expedition (1973), Snellius II (1984-1985), and the Banda Sea expedition (November 2013). Most of these expeditions focused on geological and physical oceanography. The concept of plates tectonic in the Banda Sea, for example, was founded by the SEATAR expedition [20]. This expedition identified some locations of gas, oil, and offshore mining [20]. The phenomena of Weber Basin was introduced by Galathea expedition [20]. Some marine biota such as sea cucumber (*Paroriza grevei*), polychaeta, isopods (*Macrostylis hadalis*) and (*Lepthanthura hendili*), and numphon (*Numphon femorale*) were collected during the Galathea expedition. The organic productivity of phytoplankton was the major finding of this expedition [20].

There were only 128 original research papers about Indonesian deep-sea were published since the last three centuries (1872-2017). About 9% of the papers are related with the deep-sea ecosystem of

the Banda Sea. This means there were only 0.8 articles of Indonesian deep-sea published every year. Specifically, there was only –in average– 1.3 articles about the Banda deep-Sea published every decade. The number of publication about deep-sea in Indonesia is lower than the Philippines (mean 0.9 article y^{-1}) and much lower than the United States of America (4 articles y^{-1}).

The subjects of the published paper varied. In this paper, the research topics were categorized into four categories of subject/areas for the convenience of discussion: 1) geological oceanography (e.g. geophysics, geochemistry, geo-hazard etc.); 2) physical oceanography; 3) chemical oceanography; and 4) biological oceanography (ecology, marine environment, fisheries, microbiology, marine biology). Given to limited articles focusing on integrated topics such as air-sea interaction and climate and ecosystems (deep-sea, coastal, and terrestrial) interaction, these topics included in biological and physical oceanography. The literature review revealed that almost half of the published papers (45%) are related with geological oceanography, followed by physical oceanography (32%). Plate tectonic, geomorphology, and sedimentology of the seafloor are the most common subjects of geological oceanography. The past studies on physical oceanography of deep-sea mainly focused on descriptive physical oceanography (e.g. temperature, salinity, density, etc.) and dynamics of physical oceanography (e.g. water mass motion). Research activities on biological and chemical oceanography are limited, 16% and 8%, respectively.

Generally, previous deep-sea studies described above mainly focused on basic research such as inventory and partial observation. In addition, the deep-sea studies were undertaken limited in several locations such as Sunda/Java trench in the Indian Ocean, Banda trench in Maluku, and Sulawesi basin. This means both basic and advanced research activities of deep-sea especially biological and chemical oceanography are essential. Research on marine biology, biodiversity, deep-sea ecosystem and integrated research topics such as air-sea interaction and climate and ecosystems (deep-sea, coastal, and terrestrial) interaction are required to strengthen conservation actions to ensure availability of marine resources and to mitigate climate change. Advanced research on geological and physical oceanography (e.g. geo-hazard, dynamic structure of deep-sea ecosystems, geologic and climatic prediction, etc.) are still important to support marine transportation and infrastructure development and to develop early warning system of natural disasters such as earthquake and tsunami.

Given the importance of the Banda Sea, in terms of oceanography features, the Banda Sea plays an important role in the establishing of the Indonesian Throughflow (ITF). ITF is considered to have an influence in season phenomena such El Niño Southern Oscillation (ENSO) and Asian-Australian monsoon via global ocean thermohaline circulation and a trade-off on water mass between the Pacific and the Indian Ocean [48]. Indonesian weather is also known to be influenced by oceanographic conditions through air-sea interaction in which the variability of sea surface temperature of the Banda Sea may affect the rainfall [49]. Because of its oceanography dynamics, the upwelling in the Banda Sea supports high diversity of the marine ecosystem. High concentration of chlorophyll-a lead to high productivity in which the Banda Sea has been long known as the potential fishing ground for various fisheries [50-52]. This means that integrated and comprehensive research is crucial not only to support national blue economy goals but also international scales particularly the Pacific and the Indian Ocean.

3.5. *Deep-sea research mission and challenges*

Maritime is Indonesian national development priority declared in 2014. The mission of deep-sea research in Indonesia is generating excellent scientific based information and technology to support deep-sea management, conservation, and human well-being. Deep-sea research should provide big-significant-real impacts on both human development and effective sustainable management and conservation.

The questionnaire survey showed that the proportion of publication on deep-sea is minimal (2%) with the participation level of respondent on the deep-sea research is only 25%. This finding is supported by literature review that scientific articles related to the deep sea ecosystem are very limited. Similar to literature survey, our questionnaire survey found that physical oceanography, plankton, and geological oceanography are the most common research subjects (82%) of the deep-sea publication.

Proportion and participation of respondents on international dissemination (international scientific publication, conferences, research collaboration) are much lower than local dissemination (table 1). For example, the contribution of respondents in delivering their research findings in international conferences is much lower than in national ones, 27%, and 73%, respectively. Most of the deep-sea research activities were funded by domestic research grants (64%) compare to international ones (36%).

Table 1. Capacity of human resources in publication, dissemination, and research fundraising.

Description	Mean	Proportion (%)	Participation (%)
Publication:			
<i>Publication related to deep sea</i>	0.25	2	25
<i>Publication in international journals</i>	1.38	11	44
<i>Publication in national accredited journals</i>	9.31	72	94
<i>Other publication (popular, newspaper, etc.)</i>	2.19	17	63
Scientist involvement:			
<i>Speaker at international conference</i>	1.75	27	56
<i>Speaker at national conference</i>	4.75	73	81
Funding:			
<i>External (international) research grant</i>	1.00	36	31
<i>Internal (domestic) research grant</i>	1.75	64	56

Research infrastructure (laboratories) and facilities (equipment, research vessel, research funding) are the main obstacles in the development of deep-sea research. Figure 3 illustrates the current conditions of deep-sea research infrastructure and facilities summarises a normalized to vary between 0 (not available) and 1 (good). Firstly, it is pertinent to note that research infrastructure: laboratories, equipment, research vessel, funding for research and publication are in very bad condition (< 0.5, scale 0-1). Secondly, organisation/institutional management systems and collaboration are in bad condition (0.5 – 0.75, scale 0-1). The only good conditions are human resources and literature access. This finding indicates that both current research infrastructure and institutional management system are not ideal to support deep-sea research. Significant improvements in these sectors are required to achieve the blue economic goals through the research related to the deep-sea environment.

The study identified four other challenges in the deep-sea research development associated with managerial/institutional and technical factors. Firstly, the absence of a national grand design (master plan) and strategic plan of deep-sea research resulted in the research priority remained unclear and the research topics and location are often overlapped. Secondly, the institutional and regulation framework of deep-sea research are not effective in the implementation, consequently research collaboration and dissemination do not work properly. Thirdly, lack of standardized methods and long-term replicated measurement in deep-sea research resulted in incompatible data which cannot be used for comparison or upscaling into large scales. Lastly, most of the data and output from deep-sea studies are not managed properly using standardized metadata or were inaccessible.

3.6. Grand design and strategic plan for future deep-sea research

Deep-sea research development is important for Indonesia to support national development priority in order to achieve blue economy goals. Grand design (masterplan) and strategic plan of deep-sea research are essential as a guideline for future deep-sea research. We developed a grand design and its strategic plan named Indonesian Deep-sea Research and Monitoring (I-DREAM) (figure 4). The short-term target or objective (2018-2025) of this program is improving research infrastructure and facilities and strengthening institutional systems. The long-term target or objective (2026-2045) of the program

is generating advanced scientific based information on deep-sea ecosystems to support national development priorities: food and energy security, early warning system on the status of biodiversity and ecosystems services, national defense, and disaster mitigation and adaptation.

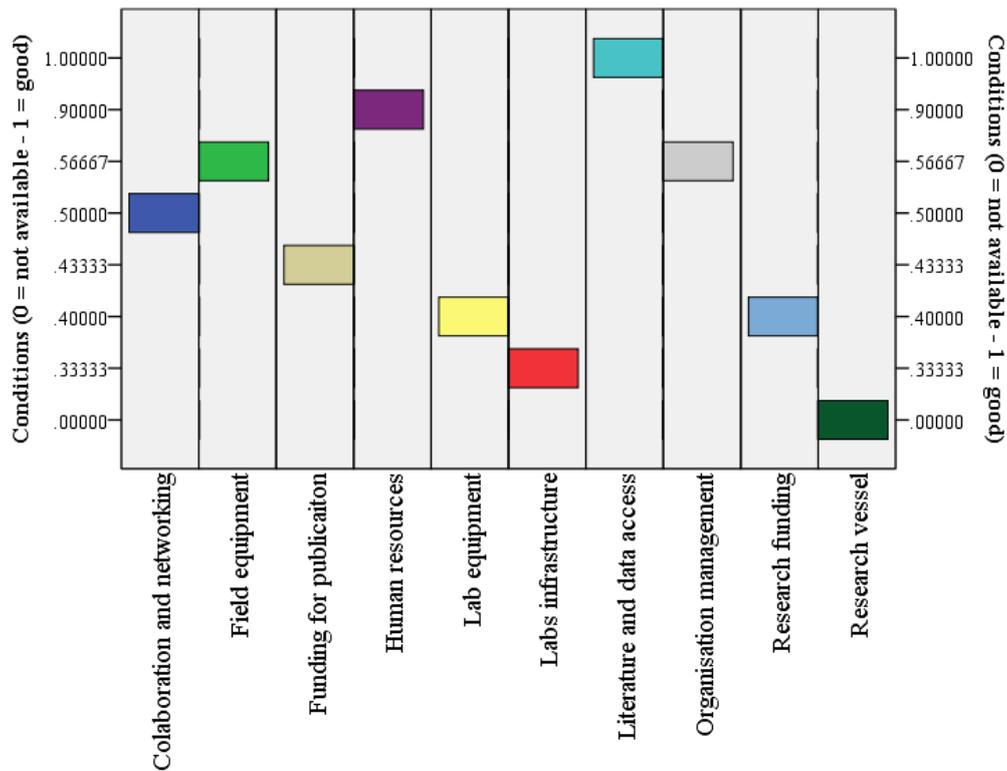


Figure 3. Current condition of deep-sea research infrastructure and facilities.

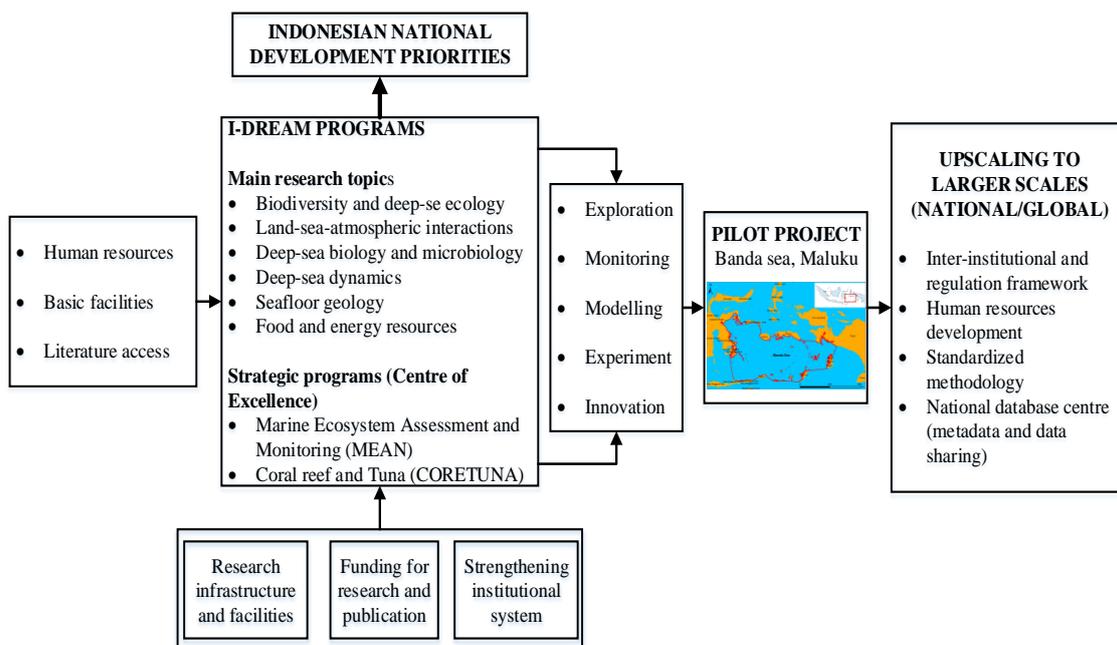


Figure 4. Concept of Indonesian Deep-sea Research and Monitoring (I-DREAM).

The study showed that human resources, access to literature, and basic facilities are available to support deep-sea research in Indonesia. These aspects are basic requirement and important to implement I-DREAM Programs. However, there are three weaknesses should be improved to support the I-DREAM programs. Firstly, improving research infrastructure and facilities such as research vessels and advanced laboratories with adequate equipment for sample collection and analysis are required as research tools. These are essential due to deep-sea zones are untouchable without using equipment (technology). Secondly, sustainable funding for research and publication is crucial to ensure long-term assessment and monitoring of deep-sea ecosystem. Lastly, strengthening institutional systems such as improving management system and efficient bureaucracy are needed for effective research and accountability. The questionnaire survey showed that improving research infrastructure and advanced equipment as the top priority (Ranking 1), followed by strengthening institutional systems and human resources development, ranking 2 and 3, respectively (figure 5a).

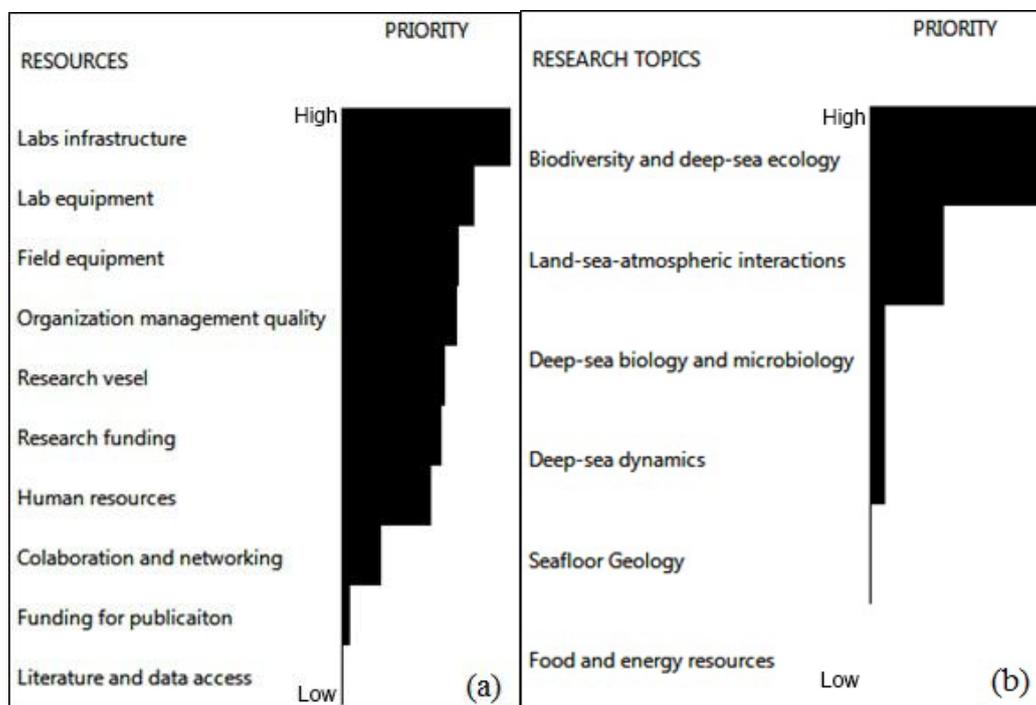


Figure 5. (a) Priority of resources to be improved to support deep-sea research and (b) priority of research topics for deep sea-research.

The questionnaire survey revealed six main research topics for deep-sea research: biodiversity and deep-sea ecology, land-sea-atmospheric interactions (including air-sea interaction and climate), deep-sea biology and microbiology, food and energy resources, deep-sea dynamics, and seafloor geology. The first four topics are associated with biological and chemical oceanography, the fifth topic is physical oceanography, and the last topic is geological oceanography. The equal proportion for the six main research topics and five research categories: exploration, monitoring, experiment, modelling, and innovation are important to provide a holistic and advanced assessment of deep-sea ecosystem (figure 6). The top priority of research topics for future is research related with biological and chemical oceanography (Ranking 1 – 3), followed by deep-sea dynamics (Ranking 4) and seafloor geology (Ranking 5) (Figure 5b). In addition, two strategic programs (figure 4): 1) Marine ecosystem assessment and monitoring (MEAN) and 2) deep-sea coral reef and tuna fisheries (CORETUNA) are suggested as the centre of excellence for deep-sea research. These strategic programs are proposed because they faced tremendous threats from climate change and direct human actions such as

overexploitation, pollution, and environmental degradation and required immediate actions to protect them [17, 18]. The centre of excellences is important to improve institutional capacity and capability in specific aspects, which, in turn, accelerate science development and its impacts on human well-being and conservation.

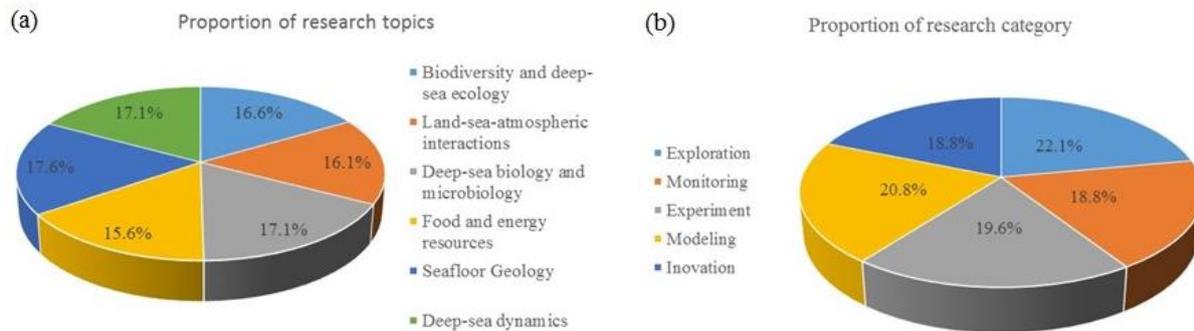


Figure 6. (a) Proportion of dee-sea research topics should be implemented and (b) proportion of research categories for future deep-sea research.

The Banda Sea was identified as a suitable core study area of the pilot project to implement I-DREAM programs because it is unique deep-sea (see section 3.1 – 3.4). The next strategic plan is upscaling the project from the Banda Sea (core study area) into larger scales (national or global scale). Upscaling is required to address global change and other environmental threats of deep-sea ecosystem. Some aspects are required for upscaling: 1) inter-institutional and regulatory framework to strengthen institutional networking and collaboration; 2) human resources development especially improving quantity and quality of deep-sea scientists; 3) establishing standardized methodology of data collection and sample analysis are required for data compatibility and data transfer; and 4) national database centre development including metadata and data exchange is needed to optimize the output of deep-sea research (figure 4).

The grand design and its strategic plan of deep-sea research are comprehensive (including all aspects of deep-sea using both literature review and questionnaire survey) and reliable. I-DREAM is a competitive and realistic program to support deep-sea conservation and sustainable use of marine resources to achieve blue economy goals. The limitation of the program and its strategic plan is on their implementations, which require strong long-term political commitment and sustained investment. However, these risks could be minimized if the government has political commitment and invest significant budget in deep-sea research.

4. Conclusions

It is clear that Indonesian deep-sea ecosystem is still underexplored. Data and publication on this ecosystem are very limited and the potential of its biological and natural resources is not well documented. Ironically, this unique ecosystem is threatened by climate change and human activities such as environmental degradation, pollution, and resources extraction. Deep-sea research development faces some obstacles and challenges such as research infrastructure/facilities are very limited and poor institutional management system. Attention and investment in deep-sea research are strongly required to support biological and natural resources security (e.g. food and energy security) and conservation. In order to encourage deep-sea research development, we develop a grand design and innovative strategic plan for deep-sea research and monitoring program. This grand design and strategic plan are comprehensive, competitive, and realistic to be applied in both small and large scales. The Banda Sea is a suitable area for a pilot project location (core area of study) of deep-sea research and then upscaled to a larger area. The grand design and its strategic plan will assist researchers (1) to generate advanced scientific data and information which important to support deep-sea management and decision-policy-making for deep-sea ecosystem, (2) to equip researchers with

standardized methods and reliable results of deep-sea research, and (3) meet the growing demand for data and information of deep-sea ecosystem conditions and its potential to achieve blue economic goals including to support conservation actions and human well-being.

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