

Hidden Depths: A Unique Biodiversity Oasis in the Persian Gulf in Need of Further Exploration and Conservation

Kaveh Samimi-Namin ^{1,2,3,*} and Bert W. Hoeksema ^{1,4}

¹ Marine Evolution and Ecology Group, Naturalis Biodiversity Center, P.O. Box 9517, 2300 RA Leiden, The Netherlands; bert.hoeksema@naturalis.nl

² Department of Zoology, University of Oxford, Oxfordshire, Oxford OX1 3SZ, UK

³ Natural History Museum, Cromwell Road, London SW7 5BD, UK

⁴ Groningen Institute for Evolutionary Life Sciences, University of Groningen, P.O. Box 11103, 9700 CC Groningen, The Netherlands

* Correspondence: kaveh.samimi@naturalis.nl

Abstract: The Persian Gulf, a young and shallow epicontinental sea, is known for its unique geological and oceanographic characteristics that foster its diverse and productive marine ecosystems. A substantial portion of the Gulf's seafloor consists of unconsolidated soft sediments, making it unsuitable for colonization by many sessile organisms. Consequently, relatively few hard grounds and submerged banks provide suitable habitats for benthic and substrate dwellers. This study documents a unique marine habitat on an offshore submerged bank, likely a raised salt dome, south of Qeshm Island, Iran. This area is home to a high concentration of ahermatypic coral species and remains relatively sheltered from human activities. The bank's geographic location allows inflow currents from the Strait of Hormuz to transport larvae and nutrients, providing suitable substrates for various sessile invertebrates. Moreover, it causes the formation of Taylor columns, which affect fluid dynamics and circulation patterns, indirectly enhancing biodiversity. Despite facing risks from large-scale regional and localized threats, the bank's remoteness from the main coast and its depth provide some protection. This study emphasizes the need for continued exploration and the implementation of effective conservation measures in the region, along with additional research to clarify the ecological and physical parameters supporting its diversity. It also presents the first in situ photographic evidence for the occurrence of some octocoral genera in the Gulf. Future research should investigate how the species compositions of hidden banks and shoals contribute to the overall biodiversity of the Persian Gulf.

Keywords: biodiversity hot spot; octocorals; deep water; submerged banks; shoals; non-scleractinians; Taylor columns

Citation: Samimi-Namin, K.; Hoeksema, B.W. Hidden Depths: A Unique Biodiversity Oasis in the Persian Gulf in Need of Further Exploration and Conservation. *Diversity* **2023**, *15*, 779. <https://doi.org/10.3390/d15060779>
Academic Editor: Pamela Hallock

Received: 1 May 2023

Revised: 13 June 2023

Accepted: 14 June 2023

Published: 15 June 2023



Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

The Persian Gulf is a relatively shallow and geologically young epicontinental sea, with distinct and extreme environmental conditions that foster the resilience of its ecosystems [1–4]. It is connected to the Indian Ocean through the Strait of Hormuz (Figure 1). This passage is crucial for the exchange of water, nutrients, and marine life between the two regions. The Gulf is known for its harsh environments and unique species composition, marked by low species diversity but a high degree of endemism compared with the rest of the Indian Ocean [5]. The Gulf's unique geological and oceanographic characteristics contribute to its diverse and productive marine ecosystems [1]. Its shallow depth, warm temperatures, and high salinity levels create distinct habitats that support a wide variety of marine life, including coral reefs, seagrass beds, and mangroves [3].

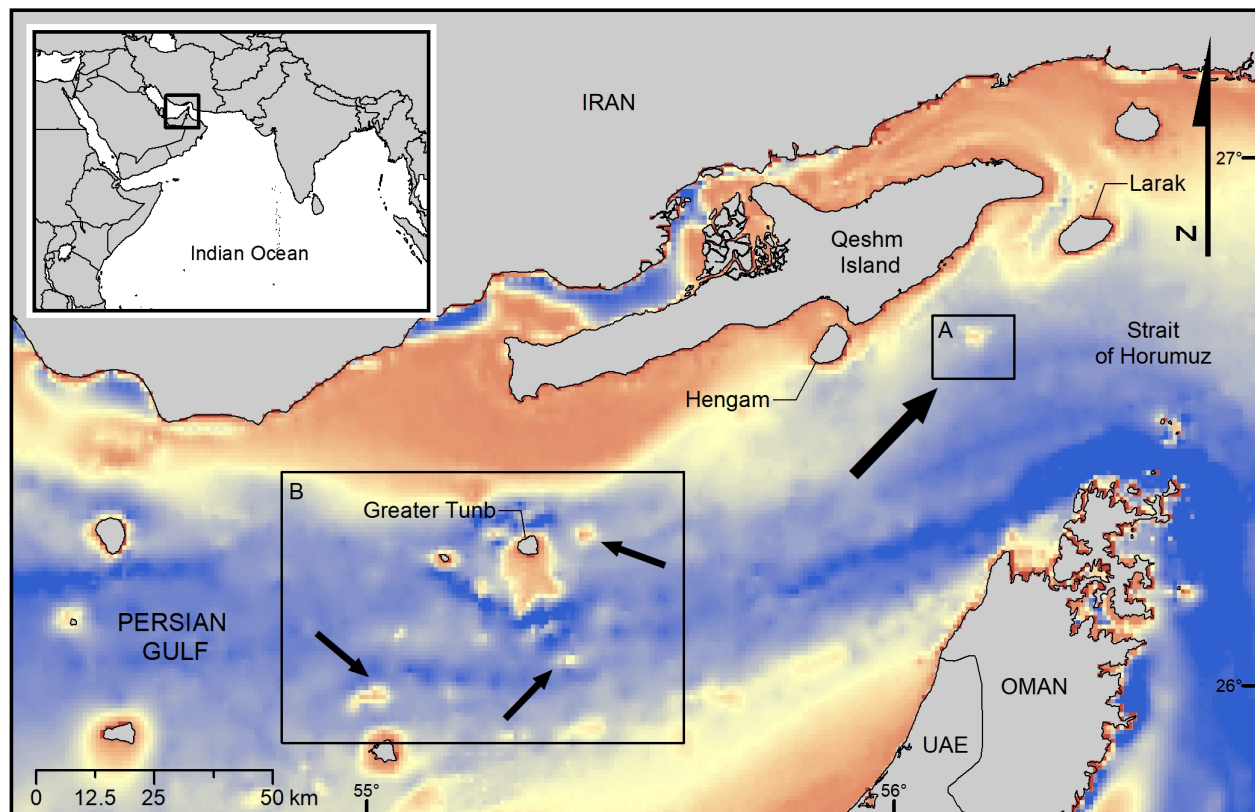


Figure 1. Bathymetric map of the eastern Persian Gulf. Brown = shallow; blue = deep. (A) The location of the submerged bank; (B) other submerged banks with potential high diversity around Greater Tunb Island indicated by arrows.

The dominant composition of the Persian Gulf's seafloor consists of soft sediments, primarily mud, silt, and sand [6]. These sediments are a result of the region's geological history and the natural processes occurring in the Gulf. The composition of the seafloor plays a crucial role in shaping the area's benthic habitats [7]. Although this soft sediment is ideal for some marine invertebrates, it limits the colonization and growth of sessile organisms. Therefore, the presence of hard grounds and submerged banks can promote species richness at a local scale. It can provide a suitable habitat for a diverse range of marine life, including fishes, corals, and various groups of other invertebrates [8], and can also offer protection from predators. Submerged banks can also influence local currents and play a role in marine ecosystem dynamics. The height of such submerged structures can affect the formation of Taylor columns in rotating fluids, resulting from the Coriolis effect [9]. While not directly increasing biodiversity, their presence can indirectly enhance ecosystems and the biodiversity around those obstacles, such as submerged banks and seamounts, through processes such as nutrient upwelling, enhanced mixing and retention, and habitat creation [10,11]. For example, circulation patterns, including those influenced by Taylor columns, can create retention zones for planktonic larvae and provide sheltered habitats, increasing their chance of settlement and eventually fostering species diversity around those objects [12].

A unique and diverse marine habitat, 17 km south of Qeshm Island and 48 km offshore from the Iranian main coast (Figure 1), was surveyed in 2015–2018 during some explorative dives. The oceanographic and bathymetric data suggest that this submerged bank is likely a raised salt dome, with the base at a depth of about 70 m and the top at 25 m below the water surface (Figure 1). Only the shallow top layer of the structure is surveyed. It was mainly composed of unconsolidated and partial-consolidated sand, gravel, pebbles, and cobbles, providing a suitable habitat for various marine sessile organisms

surrounded by a sandy–muddy seafloor. The top and upper edges of the bank were densely populated by various sessile organisms, forming a thriving animal forest (Figures 2–4). It was covered by a diverse and dense population of octocorals, antipatharians, sponges, solitary scleractinians, and other invertebrates (Figures 2–4). Spanning an area of about 35 km² (0.01% of the total Persian Gulf area), the surveyed site represents the highest concentration of ahermatypic (non reef-building) coral species ever documented in the Persian Gulf [13,14]. Upon an initial evaluation of the available images and video fragments, and prior to sampling the area, the estimated species richness for octocorals is anticipated to be 40–60 species. Additionally, this study presents the first in situ photographic evidence for the occurrence of the octocoral genera *Ellisella*, *Solenocaulon*, and *Verrucella* in the Gulf (Figures 2–4). While previous records of these genera exist [13,14], they are notably uncommon and predominantly found in deeper waters.

Owing to its geographical location, the bank receives inflow currents from the Strait of Hormuz containing larvae and nutrients, and its hard grounds provide a suitable substrate for larval attachment. This area can act as a source of larvae and potentially seed downstream areas. To our knowledge, no other similar habitat with such diversity has been reported in the Gulf region.

The surveyed area is likely at risk due to large-scale environmental changes, similar to other regions of the Persian Gulf [3,15–17]. On a more localized level, small-scale threats may stem from various fishing activities and recreational diving, which may lead to habitat degradation; however, the area's considerable distance offshore and its greater depth act as protective factors, making it less likely to be adversely affected by these activities.

The northern side of the Gulf, despite having higher diversity compared to the southern part, remains understudied [3,18]. The growing number of publications on the Gulf's biodiversity, covering various groups of marine organisms [13,14,19–24], highlights the need for the further exploration and conservation of deep and remote areas. For example, a recent survey off the coast of Qatar resulted in the documentation of another unique coral community, which was dominated by an aggregation of two mushroom coral species, one of which was previously unknown in the Gulf [25].

The present study confirms the existence of unsurveyed, deeper, remote marine habitats in the Persian Gulf, and their potential value in supporting marine life. Given the presence of numerous submerged banks, shoals, salt diapirs, and depositional features [2,26,27], it is highly probable that other undiscovered structures with similar characteristics and high diversity exist in the region (Figure 1). A lack of information on these deeper geomorphic banks may lead to the underestimation of the extent of suitable habitats and species diversity in the Gulf region. Therefore, it is crucial to study these submerged banks as they can support large, diverse coral communities [8] and potentially serve as vital refuges from environmental disturbances [28,29].

Given the importance of preserving this unique marine biodiversity hotspot, it is essential for authorities and stakeholders to implement effective conservation measures. These measures could include regulating fishing activities, raising awareness about the area's ecological significance, and developing long-term strategies to monitor and protect its ecosystem. Further investigations are underway to understand the ecological and physical parameters supporting this high-diversity habitat and investigate the species richness of corals and other marine biota.

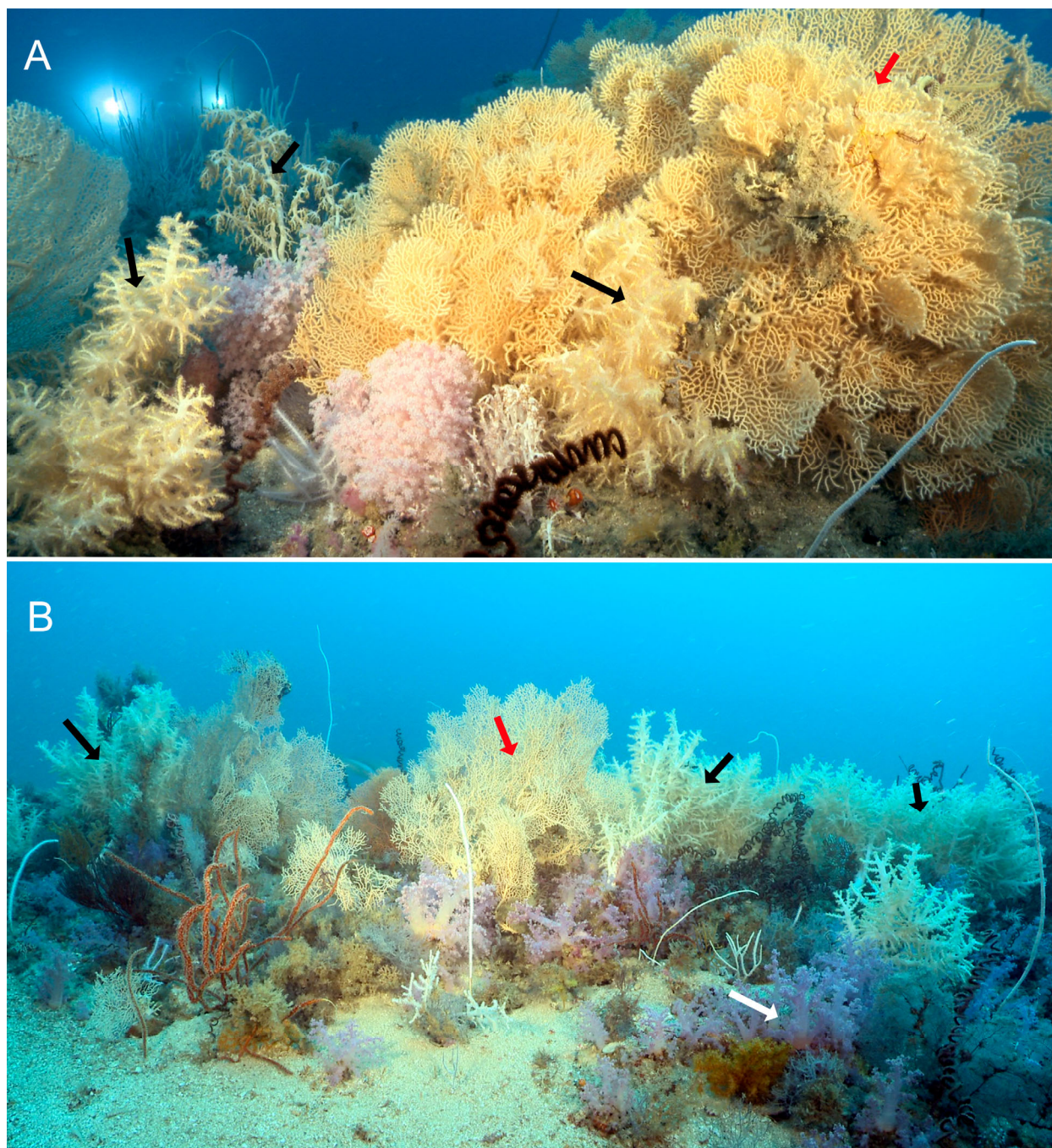


Figure 2. (A,B) Wide-angle view of the habitat (depth of 25–35 m), mainly covered by octocorals and antipatharians. (A) *Verrucella* colonies on the right (red arrow) and *Solenocaulon* colonies (black arrows); (B) *Verrucella* colonies (red arrow), *Solenocaulon* colonies (black arrows) in the background, and Nephtheids (white arrow). (Photos: A. J. Abdipour).

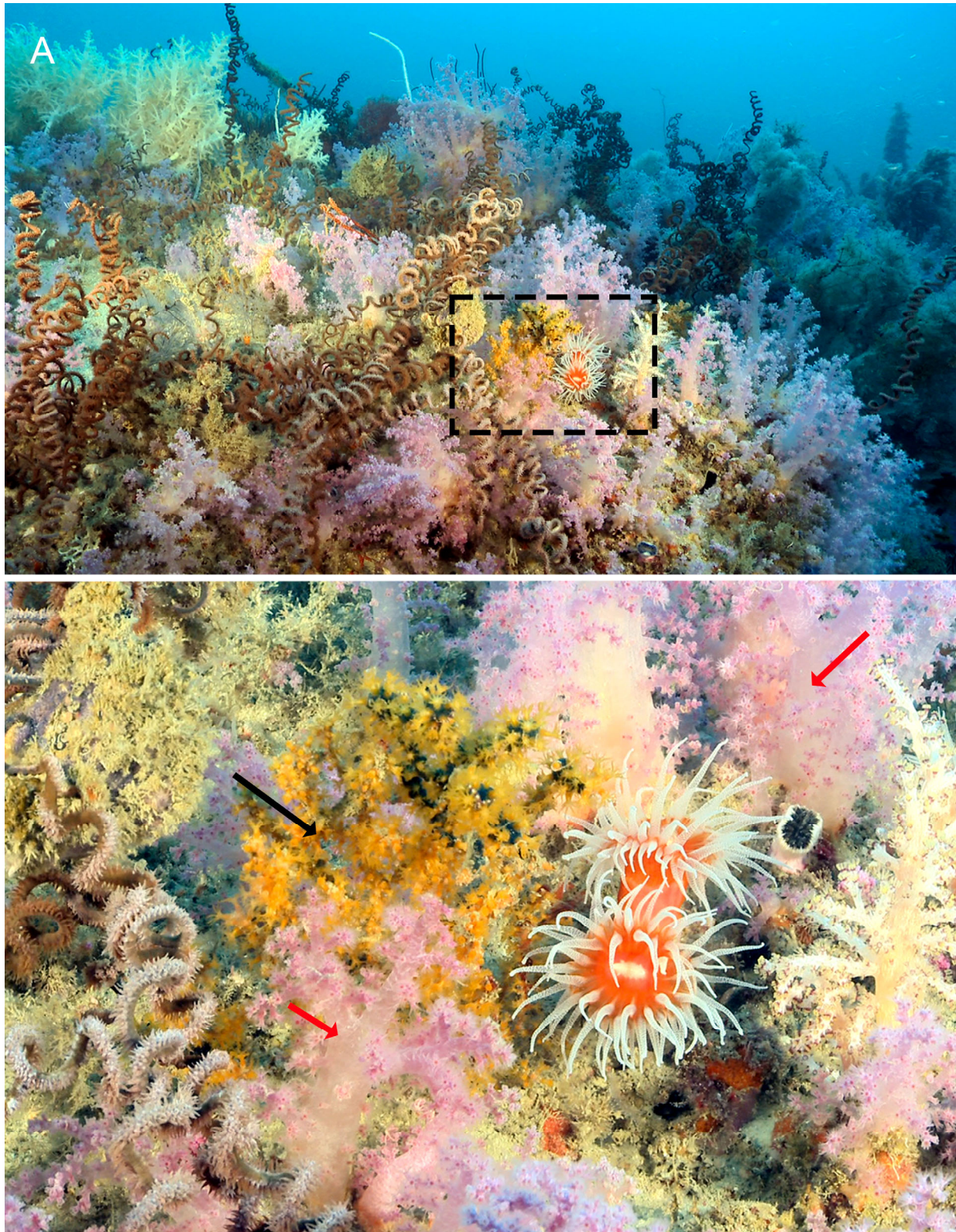


Figure 3. (A) High-density coverage of the habitat on a macro- and microscale (depth of 30–40 m), with the substrate mainly covered by octocorals and antipatharians. (B) Nephtheids (red arrow), *Astrogorgia* (black arrow), antipatharians, etc.; the solitary scleractinian corals are two *Balanophyllia* sp. (orange) and one *Paracyathus rotundatus* (black center). (Photos: A. J. Abdipour).

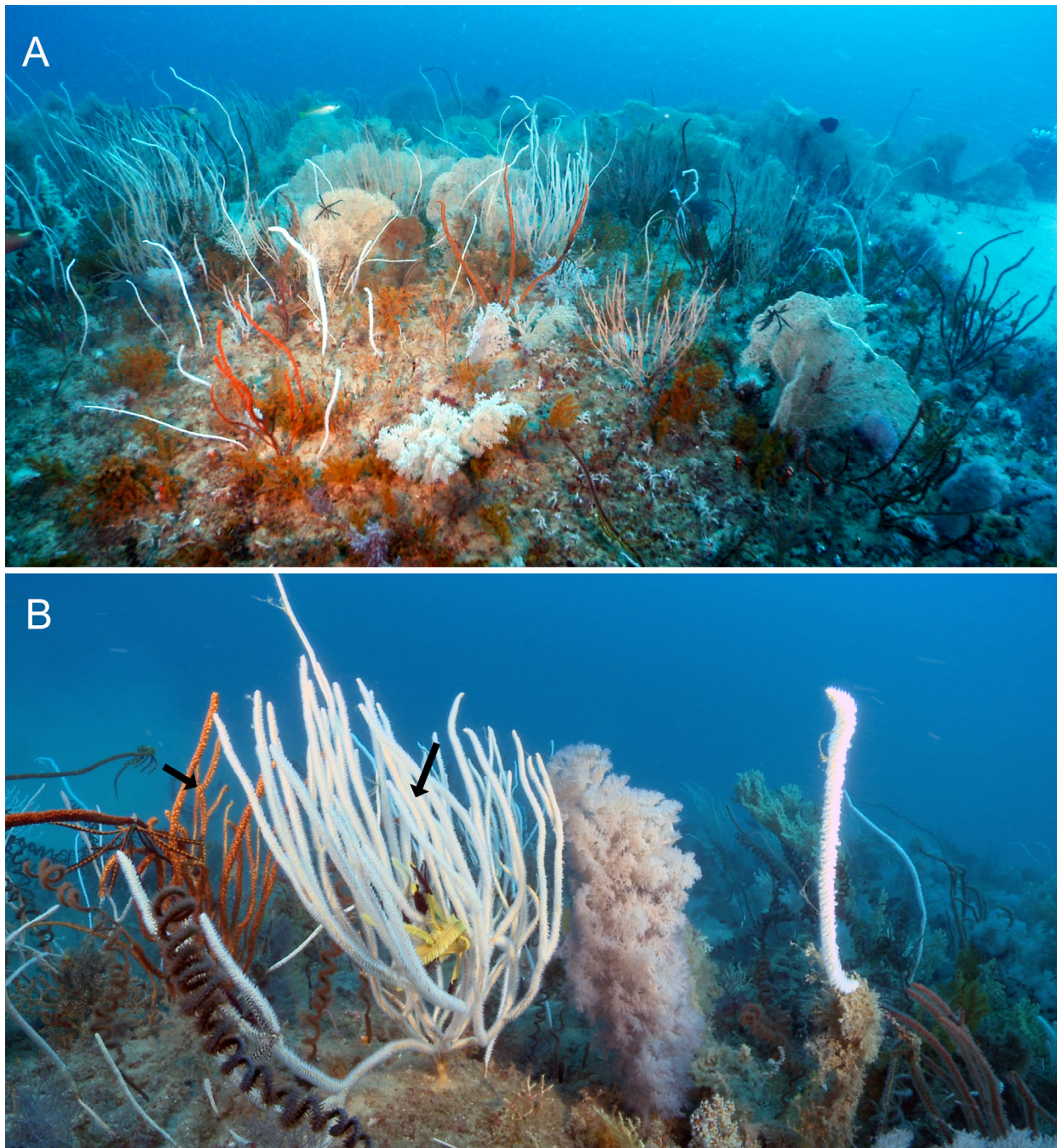


Figure 4. (A) Wide-angle view of the habitat (depth of 30–40 m), mainly covered by octocorals and antipatharians. (B) *Ellisella* colonies (black arrows). (Photos: A. J. Abdipour.)

Author Contributions: Conceptualization, K.S.-N. and B.W.H.; methodology, K.S.-N. and B.W.H.; validation, K.S.-N. and B.W.H.; formal analysis, K.S.-N. and B.W.H.; investigation, K.S.-N. and B.W.H.; data curation, K.S.-N.; writing—original draft preparation, K.S.-N. and B.W.H.; writing—review and editing, K.S.-N. and B.W.H.; visualization, K.S.-N. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The provided photos are snippets of a documentary on marine life in the Persian Gulf called *Exploring the Depths* by Ali J. Abdipour (Pendar Film, Intercut Film). The first author acted as a scientific advisor and is grateful for having participated in the production of the documentary. M.S. Ranjbar (Persian Gulf Biotechnology Park) and S.M. Dakhteh (Qeshm Free Area) are acknowledged for their support and facilitating the field work. First author's research at Naturalis was supported by the Richard Lounsbery Foundation, H. Ausubel (Rockefeller University), and L. Brown (Lounsbery Foundation) are greatly appreciated for their continued support and encouragement.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of the data; in the writing of the manuscript; or in the decision to publish the results.

References

- Purkis, S.J.; Riegl, B.M. Geomorphology and reef building in the SE Gulf. In *Coral Reefs of the Gulf: Adaptation to Climatic Extremes*; Riegl, B.M., Purkis, S.J., Eds.; Springer: Amsterdam, The Netherlands, 2012; pp. 33–50. https://doi.org/10.1007/978-94-007-3008-3_3.
- Evans, G. A discussion concerning the floor of the northwest Indian Ocean—The recent sedimentary facies of the Persian Gulf region. *Phil. Trans. A Math. Phys. Eng. Sci.* **1966**, *259*, 291–298. <https://doi.org/10.1098/rsta.1966.0014>.
- Sheppard, C.; Al-Husiani, M.; Al-Jamali, F.; Al-Yamani, F.; Baldwin, R.; Bishop, J.; Benzoni, F.; Dutrieux, E.; Dulvy, N.K.; Durvasula, S.R. V.; et al. The Gulf: A young sea in decline. *Mar. Pollut. Bull.* **2010**, *60*, 13–38. <https://doi.org/10.1016/j.marpolbul.2009.10.017>.
- Bouwmeester, J.; Riera, R.; Range, P.; Ben-Hamadou, R.; Samimi-Namin, K.; Burt, J.A. Coral and reef fish communities in the thermally extreme Persian/Arabian Gulf: Insights into potential climate change effects. In *Perspectives on the Marine Animal Forests of the World*; Springer: Cham, Switzerland, 2021; pp. 63–86. https://doi.org/10.1007/978-3-030-57054-5_3/FIGURES/6.
- Price, A.R.G. Simultaneous “hotspots” and “coldspots” of marine biodiversity and implications for global conservation. *Mar. Ecol. Prog. Ser.* **2002**, *241*, 23–27. <https://doi.org/10.3354/meps241023>.
- Purser, B.H. *The Persian Gulf: Holocene Carbonate Sedimentation and Diagenesis in a Shallow Epicontinental Sea*; Springer: Berlin, Germany, 1973. <https://doi.org/10.1007/978-3-642-65545-6>.
- Sheppard, C.; Price, A.; Roberts, C. *Marine Ecology of the Arabian Region: Patterns and Processes in Extreme Tropical Environments*; Academic Press: London, UK, 1992.
- Harris, P.T.; Bridge, T.C.L.; Beaman, R.J.; Webster, J.M.; Nichol, S.L.; Brooke, B.P. Submerged banks in the Great Barrier Reef, Australia, greatly increase available coral reef habitat. *ICES J. Mar. Sci.* **2013**, *70*, 284–293. <https://doi.org/10.1093/icesjms/fss165>.
- Taylor, G.I. Stability of a viscous liquid contained between two rotating cylinders. *Phil. Trans. A Math. Phys. Char.* **1923**, *223*, 289–343.
- Genin, A.; Dayton, P.K.; Lonsdale, P.F.; Spiess, F.N. Corals on seamount peaks provide evidence of current acceleration over deep-sea topography. *Nature* **1986**, *322*, 59–61. <https://doi.org/10.1038/322059a0>.
- White, M.; Bashmachnikov, I.; Arstegui, J.; Martins, A. Physical processes and seamount productivity. In *Seamounts: Ecology, Fisheries Conservation*; Pitcher, T.J., Morato, T., Hart, P.J.B., Clark, M.R., Haggan, N., Santos, R.S., Eds.; Blackwell Publishing: Oxford, UK, 2007; pp. 62–84.6.
- Rogers, A.D. The biology of seamounts. *Adv. Mar. Biol.* **1994**, *30*, 305–350.
- Samimi-Namin, K.; van Ofwegen, L. The octocoral fauna of the Gulf. In *Coral Reefs of the Gulf: Adaptation to Climatic Extremes*; Riegl, B.M., Purkis, S.J., Eds.; Springer: Amsterdam, The Netherlands, 2012; pp. 225–252, Volume 3.
- Samimi-Namin, K.; van Ofwegen, L.P. Some shallow water octocorals (Coelenterata: Anthozoa) of the Persian Gulf. *Zootaxa* **2009**, *2058*, 1–52. <https://doi.org/10.11646/zootaxa.2058.1.1>.
- Van Lavieren, H.; Burt, J.; Feary, D.A.; Cavalcante, G.; Marquis, E.; Benedetti, L.; Trick, C.; Kjerfve, B.; Sale, P.F. *Managing the Growing Impacts of Development on Fragile Coastal and Marine Ecosystems: Lessons from the Gulf*; United Nations University—Institute for Water, Environment and Health: Hamilton, ON, Canada, 2011.
- Sale, P.F.; Feary, D.A.; Burt, J.A.; Bauman, A.G.; Cavalcante, G.H.; Drouillard, K.G.; Kjerfve, B.; Marquis, E.; Trick, C.G.; Usseglio, P.; et al. The growing need for sustainable ecological management of marine communities of the Persian Gulf. *Ambio* **2011**, *40*, 4–17. <https://doi.org/10.1007/s13280-010-0092-6>.
- Wabnitz, C.C.C.; Lam, V.W.Y.; Reygondeau, G.; Teh, L.C.L.; Al-Abdulrazzak, D.; Khalfallah, M.; Pauly, D.; Palomares, M.L.D.; Zeller, D.; Cheung, W.W.L. Climate change impacts on marine biodiversity, fisheries and society in the Arabian Gulf. *PLoS ONE* **2018**, *13*, e0194537. <https://doi.org/10.1371/journal.pone.0194537>.
- Feary, D.A.; Burt, J.A.; Bauman, A.G.; Al Hazeem, S.; Abdel-Moati, M.A.; Al-Khalifa, K.A.; Anderson, D.M.; Amos, C.; Baker, A.; Bartholomew, A.; et al. Critical research needs for identifying future changes in Gulf coral reef ecosystems. *Mar. Pollut. Bull.* **2013**, *72*, 406–416. <https://doi.org/10.1016/j.marpolbul.2013.02.038>.
- Samimi-Namin, K.; van Ofwegen, L.P. Overview of the genus *Briareum* (Cnidaria, Octocorallia, Briareidae) in the Indo-Pacific, with the description of a new species. *Zookeys* **2016**, *557*, 1–44. <https://doi.org/10.3897/zookeys.557.6298>.
- Samimi-Namin, K.; van Ofwegen, L.P. A revision of *Trimuricea* Gordon, 1926 (Cnidaria: Octocorallia: Plexauridae) with the description of six new species. *Zootaxa* **2016**, *4105*, 1–44. <https://doi.org/10.11646/zootaxa.4105.1.1>.

21. Samimi-Namin, K.; van Ofwegen, L.P. The second observation of a live *Trimuricea* species (Octocorallia: Plexauridae). *Coral Reefs* **2009**, *28*, 517. <https://doi.org/10.1007/s00338-009-0471-2>.
22. Baradari, H.; Nasrolahi, A.; Taylor, P.D. Cheilostome Bryozoa of the northern Persian Gulf, Iran. *Zootaxa* **2019**, *4619*, 459–486. <https://doi.org/10.11646/zootaxa.4619.3.3>.
23. Dehghani, A.; Sari, A.; Naderloo, R. Three new species of narrowly endemic snapping shrimp, genus *Alpheus* (Decapoda: Caridea: Alpheidae) from the Persian Gulf. *J. Mar. Biol. Assoc. U. K.* **2019**, *99*, 911–920. <https://doi.org/10.1017/S0025315418000978>.
24. Naderloo, R.; Sari, A. Subtidal crabs of the Iranian coast of the Persian Gulf: New collections and biogeographic considerations. *Aquat. Ecosyst. Health Manag.* **2007**, *10*, 341–349. <https://doi.org/10.1080/14634980701514620>.
25. Hoeksema, B.W.; Bouwmeester, J.; Range, P.; Ben-Hamadou, R. A large aggregation of self-fragmenting mushroom corals in the Arabian/Persian Gulf. *Ecology* **2018**, *99*, 1236–1238. <https://doi.org/10.1002/ecy.2139>.
26. Kent, P.E. The salt plugs of the Persian Gulf region. *Trans. Leicester Lit. Phil. Soc.* **1970**, *64*, 56–88.
27. Kent, P.E. Recent studies of South Persian salt plugs. *Bull. Am. Assoc. Petrol. Geol.* **1985**, *42*, 2951–2972. <https://doi.org/10.1306/0BDA5C2D-16BD-11D7-8645000102C1865D>.
28. Riegl, B.; Piller, W.E. Possible refugia for reefs in times of environmental stress. *Int. J. Earth Sci.* **2003**, *92*, 520–531. <https://doi.org/10.1007/s00531-003-0328-9>.
29. Bridge, T.; Guinotte, J. *Mesophotic Coral Reef Ecosystems in the Great Barrier Reef World Heritage: Their Potential Distribution and Possible Role as Refugia from Disturbance*; Great Barrier Reef Marine Park Authority: Townsville, Australia, 2012.

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.