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Introduction to Marine Biotechnology and Digitalization

Department of Biology
Faculty of Mathematics and Natural Sciences
Universitas Indonesia

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Content

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Summary

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Marine biotechnology is gaining global attention for its potential to address climate change, food security, and sustainable development. Governments are increasingly including it in national strategies for innovation and economic growth. At the same time, digital technologies such as AI, bioinformatics, remote sensing, and digital twins are transforming the field by enabling faster, more precise research and real-time monitoring of marine ecosystems. These tools improve aquaculture, enhance genetic analysis, and support sustainable resource use. The integration of digitalization ensures that marine biotechnology evolves in a way that is not only innovative and efficient but also environmentally responsible and sustainable.

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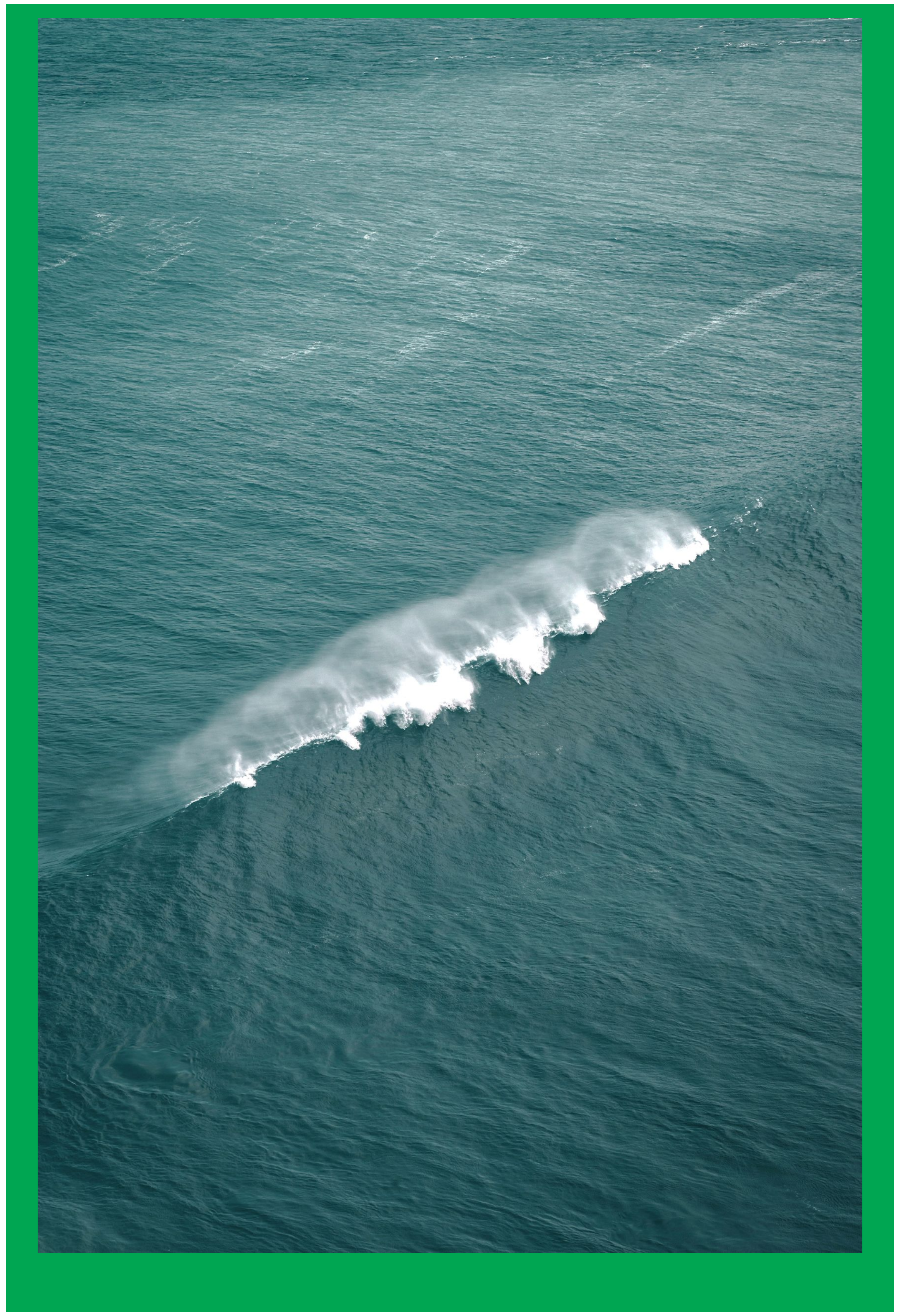
Introduction

Objective:

- Analyze marine biotechnology applications in the blue economy (bioplastics).
- Apply GIS to assess biodiversity and marine resources.



Learning Outcomes:

- (CLO1) Explain the principles and innovations in marine biotechnology and their relevance to biodiversity and the blue economy.
- (CLO2) Analyze the use of digital tools such as GIS and omics technologies in exploring and managing marine biological resources.

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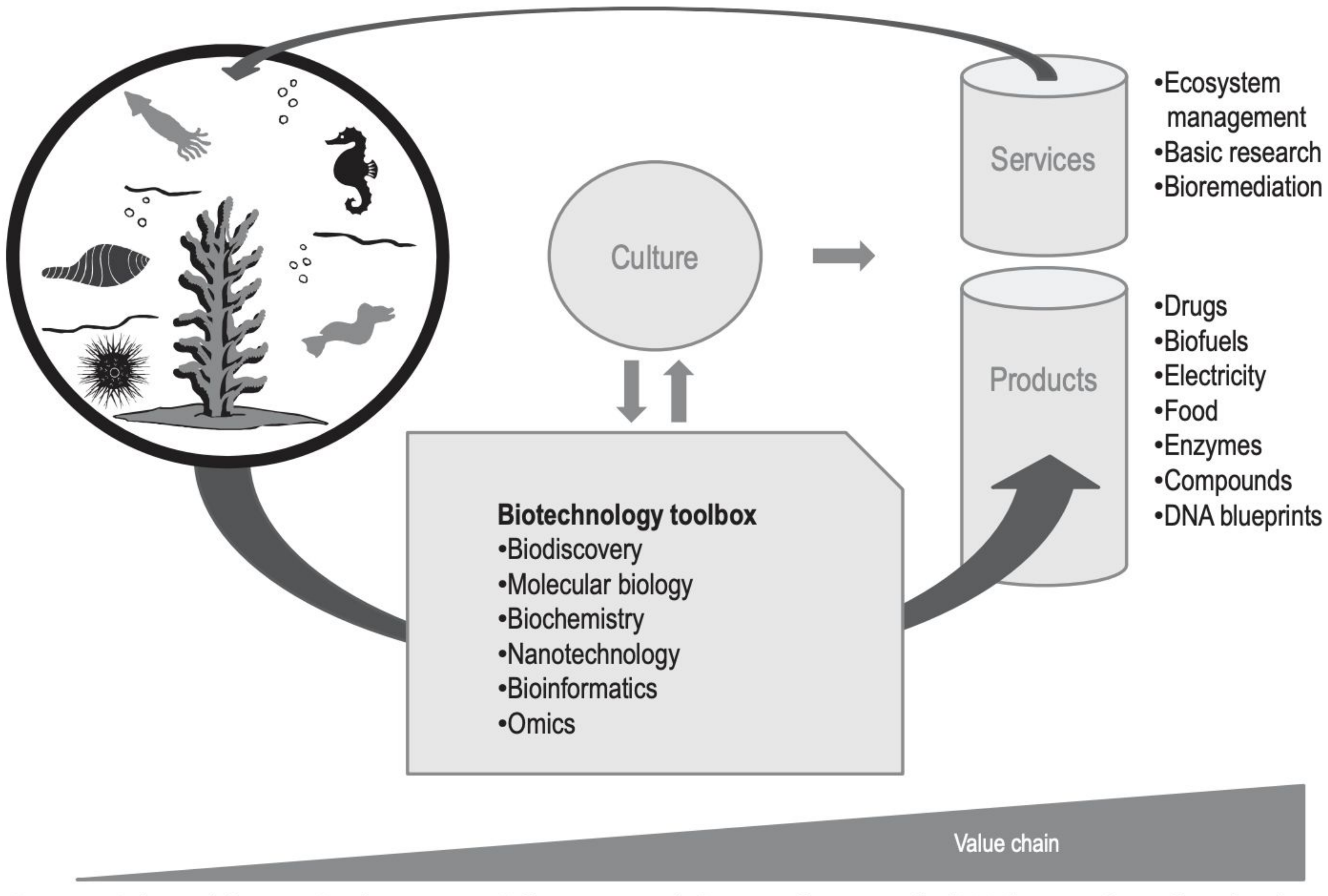
Introduction



[Taken from: ESF 2010 in OECD 2013]

In the last 60 years, biotechnology has yielded some notable advances in medicine, cosmetics, nutraceuticals, food production, and industrial applications such as biorefining. The applications of marine biotechnology are also wide-ranging, such as the production of food and biofuels (agricultural biotechnology), the development of new drugs (health biotechnology), the development of new materials (industrial biotechnology), and the development of bioremediation technologies (environmental biotechnology).

This suggests that marine biotechnology can help to address global challenges related to food, fuel security, population health and sustainable industrial processes. Recent advances in science and technology have raised interest in marine biotechnology as a new source of innovation and economic growth.

(OECD 2013)

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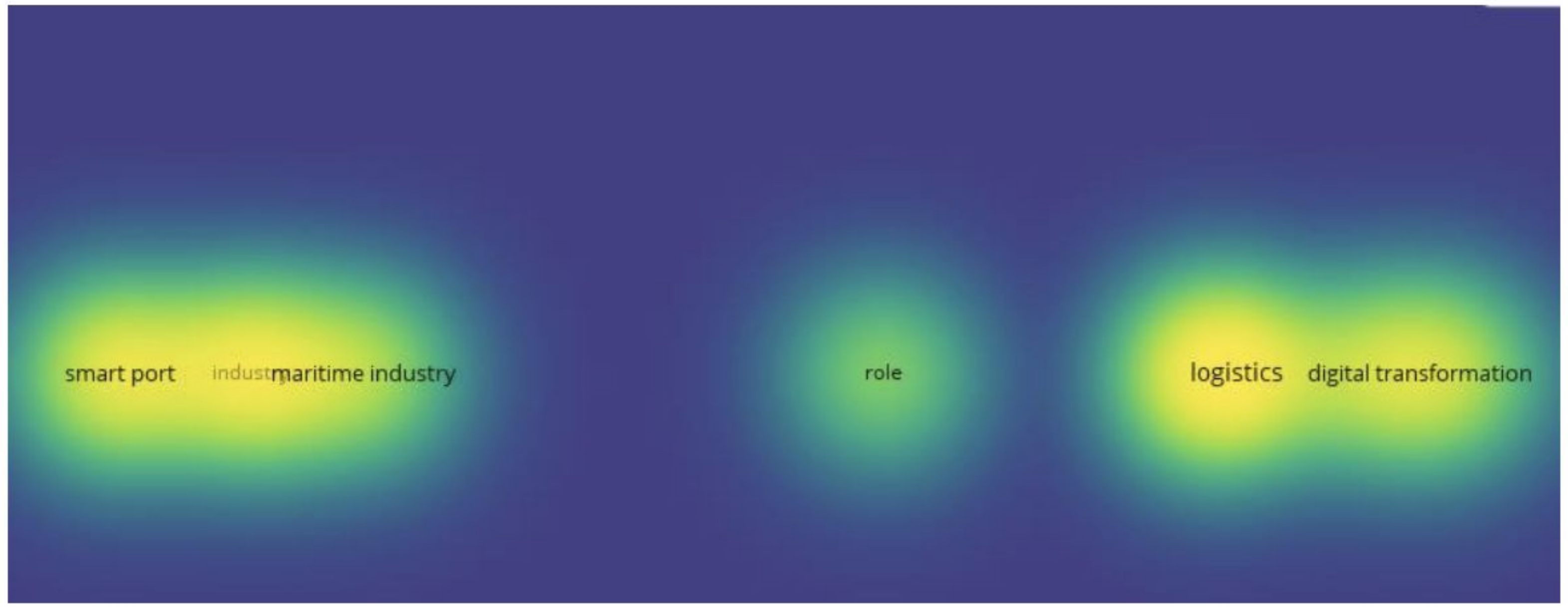
Digitalization in The Marine Industries



Frequency of Most Discussed Topic in Maritime Research during 2015-2024
[Taken from: Yusuf & Syaifullah 2025]

Note:
The larger the size of the topic in the visualization, the higher the frequency of its occurrence in the publications analyzed.

Digitalization in the marine industries refers to the integration of digital technologies into operations, research, and management. Its applications can increase the efficiency of marine production activities and reduce resource waste. For instance, intelligent fishing systems combined with real-time data analysis can accurately monitor fishery resource conditions, achieve sustainable management, and rationally use fishery resources, thereby promoting the green development of the marine economy.

On the other hand, by establishing sophisticated monitoring systems, digital technologies enhance the capability for immediate surveillance and evaluation of the marine environment, facilitating early detection and response to environmental issues such as pollution and ocean acidification.

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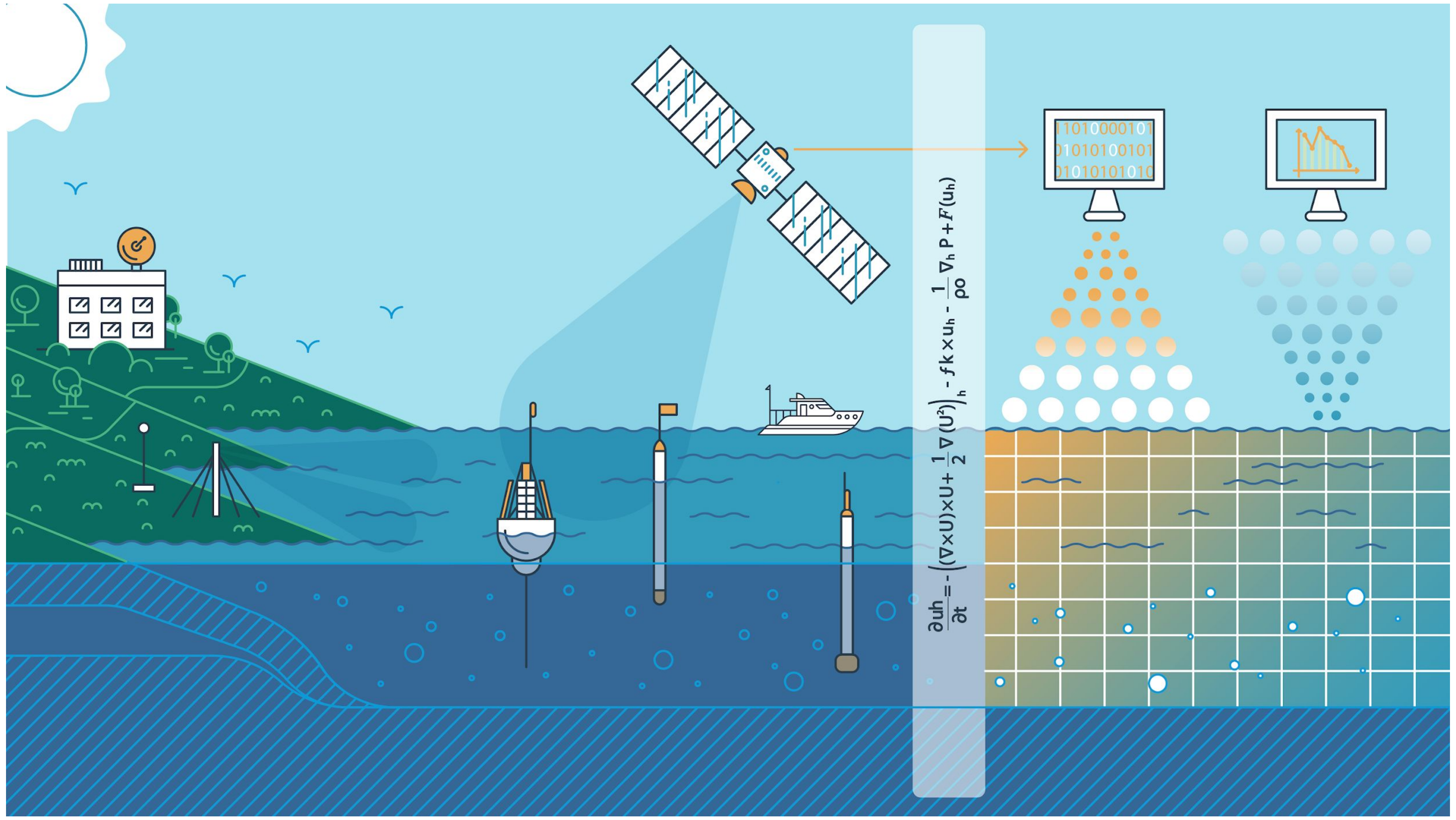
Data Collection in Marine Environment

The collection of marine environmental data consist of parameter's on::

1. **Physical Parameter**: temperature, salinity, depths, waves, currents, ice cover and thickness
2. **Chemical Parameter**: pH levels, dissolved oxygen, carbon dioxide levels, nutrients
3. **Biological Parameter**: species composition and abundance, habitat mapping, chlorophyll
4. **Geological and Geophysical Parameter**: Seafloor mapping, tectonic activity, sediment composition and thickness, magnetic (resonance?)



[Taken from: https://marine.copernicus.eu/explainers/operational-oceanography/monitoring-forecasting]

(Roach 2009)

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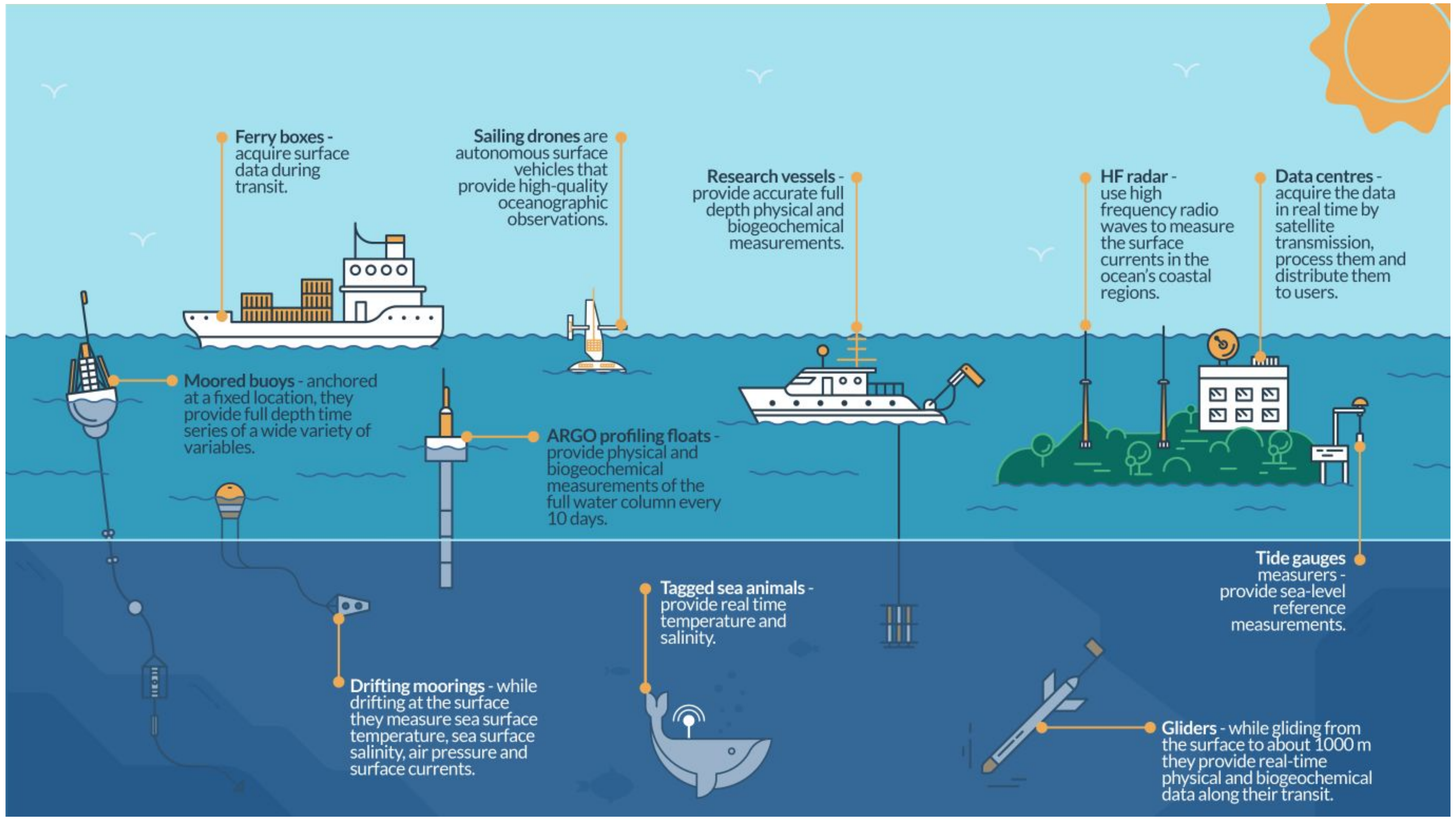
Data Collection in Marine Environment



[Taken from: https://marine.copernicus.eu/explainers/operational-oceanography/monitoring-forecasting/in-situ]

In Situ Data Collection

Data that is directly collected from the ocean using various types of instruments and platforms. This method gives data with high accuracy and reliability. Additionally, it also captures temporal changes in situ.

Moorings, buoys, and tidal Gauges collect surface and sub-surface ocean data such as wind speed, temperature, water level, etc. These sensors can be used for early tsunami detection, weather forecasting, and ocean navigation. However, the deployment and maintenance of in situ platforms can be expensive, time-consuming, weather-dependent, and spatially limited. Therefore, ex-situ data collection is used to overcome these limitations.

(Amani *et al.* 2022; Haupt *et al.* 2022)

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Data Collection in Marine Environment

[Taken from: Alshareef, Elbeshehy & Alshehri 2021

Ex Situ Data Collection

Data that were collected from marine environment are stored in laboratories and in controlled facilities. This method allows researchers to conduct detailed analysis and experiments under controlled conditions.

For example, water, sediments, or marine organisms (like algae or microbes) can be collected from the ocean and brought to a lab for chemical, biological, or genetic testing. In marine biotechnology, ex-situ methods are essential for culturing marine microorganisms, analyzing DNA sequences, and testing reactions to different environmental conditions (e.g., temperature or pH).

Another form of ex-situ data collection is remote sensing, which gathers data from a distance using satellites, drones, or aircraft. Ex-situ data collection enables high precision analysis and manipulation of variables, which is difficult to achieve in situ. However, it may not fully replicate the complexity of natural ocean environments. Therefore, it is often used to complement in situ data for a more comprehensive understanding of marine systems.

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Data Collection in Marine Environment

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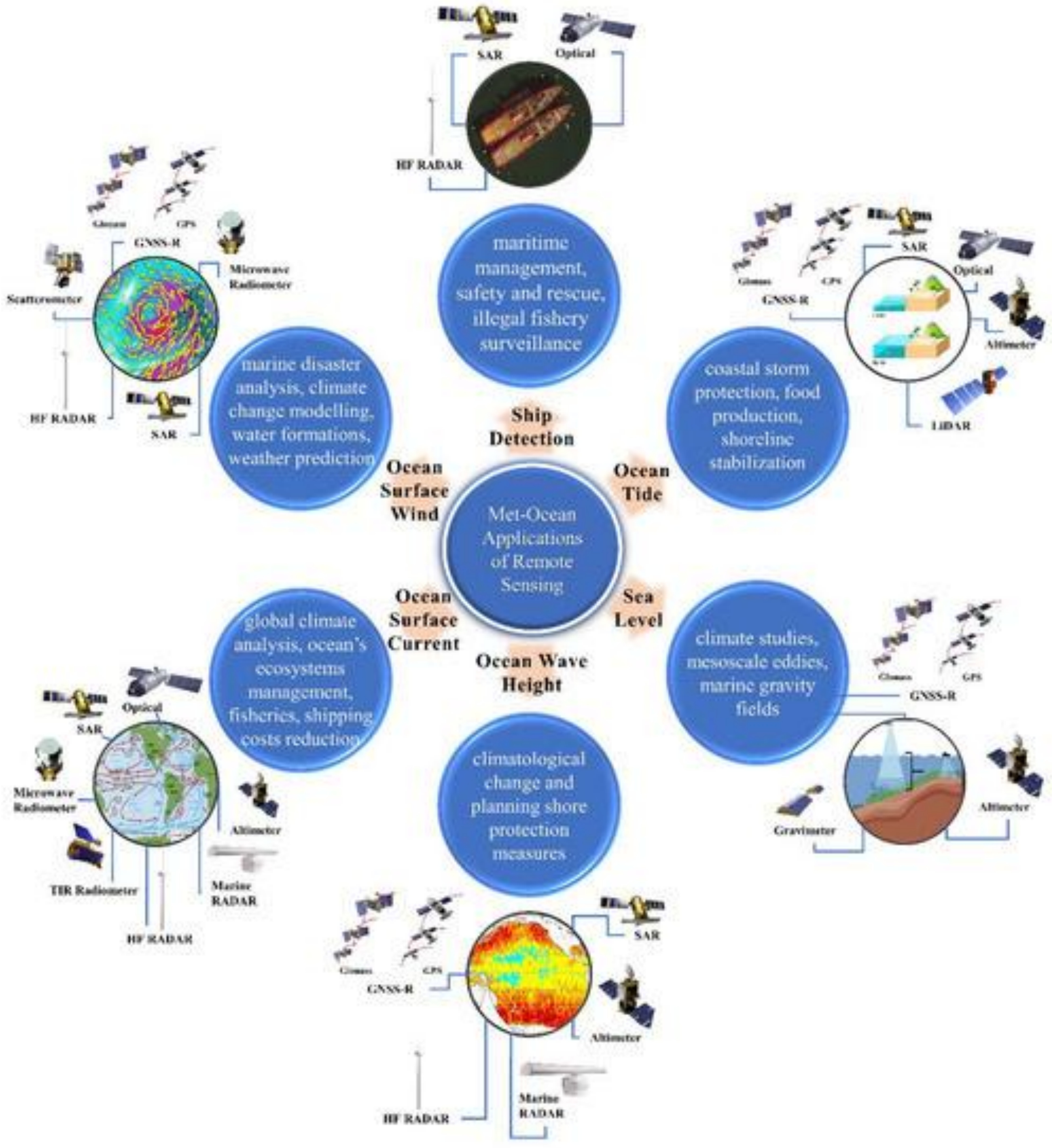
Satellite Remote Sensing

The key advantages are the large area coverage, wide range of temporal and spatial resolutions, and the low cost of derived datasets. Passive sensors are used to derive parameters such as ocean colour, bathymetry, and sea surface topography. For instance, TIR (Thermal infrared sensors) can provide sea surface temperature (SST) and ocean colour satellite observations.

Active sensors, such as Synthetic Aperture Radar (SAR), have a day-and-night imaging capability and operate in all weather conditions. These sensors have been used to detect a variety of features, such as oil spills, plastic pollution, and ships in the ocean.



[Taken from: Amani *et al.* 2022]

(Amani *et al.* 2022; Haupt *et al.* 2022)

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Data Collection in Marine Environment

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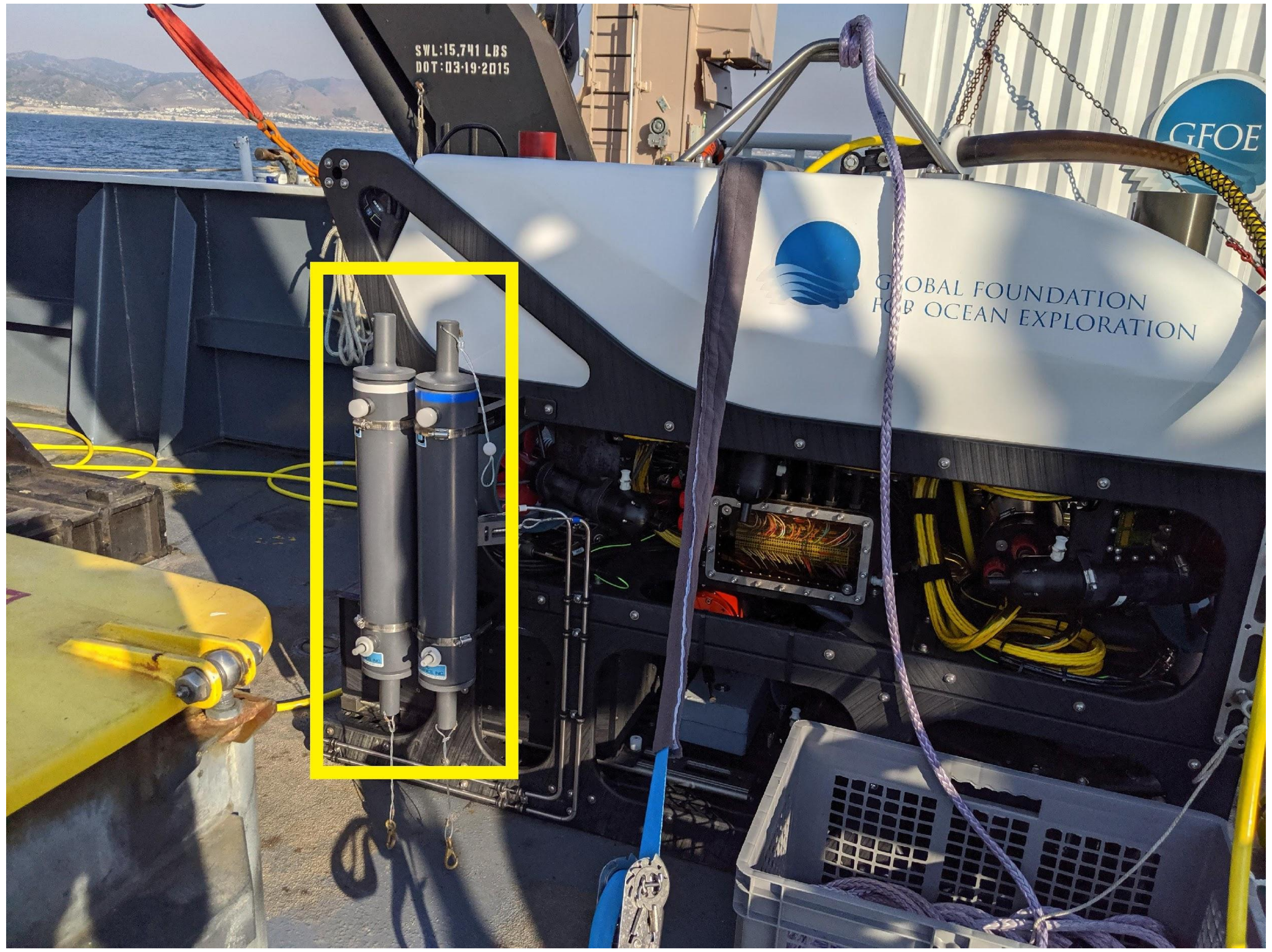
Environmental DNA (eDNA)

This data is collected from genetic material shed by organisms into their environment. Samples used are mucus, feces, or tissue particles and collected by a non-invasive method.

eDNA helps us identify organisms and characterize their role in the area's food web and ecosystem. Moreover, it can also monitor water quality and the amount of harmful bacteria in the water samples, and commercial fisheries can use it to inform their location selection and fishing practices.



Niskin Bottles
[Taken from: https://oceanexplorer.noaa.gov/technology/edna/edna.html]

Note:
water sampling tool that can be used for eDNA collection

(https://oceanexplorer.noaa.gov/technology/edna/edna.html)

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Data Analysis in Marine Environment

Data analysis seeks to convert raw observations – numerical readings, visual records, acoustic signatures, and biological samples – into actionable insights about complex marine systems for understanding phenomena like marine heatwaves, shifts in species distribution, and the health of sensitive ecosystems such as coral reefs.

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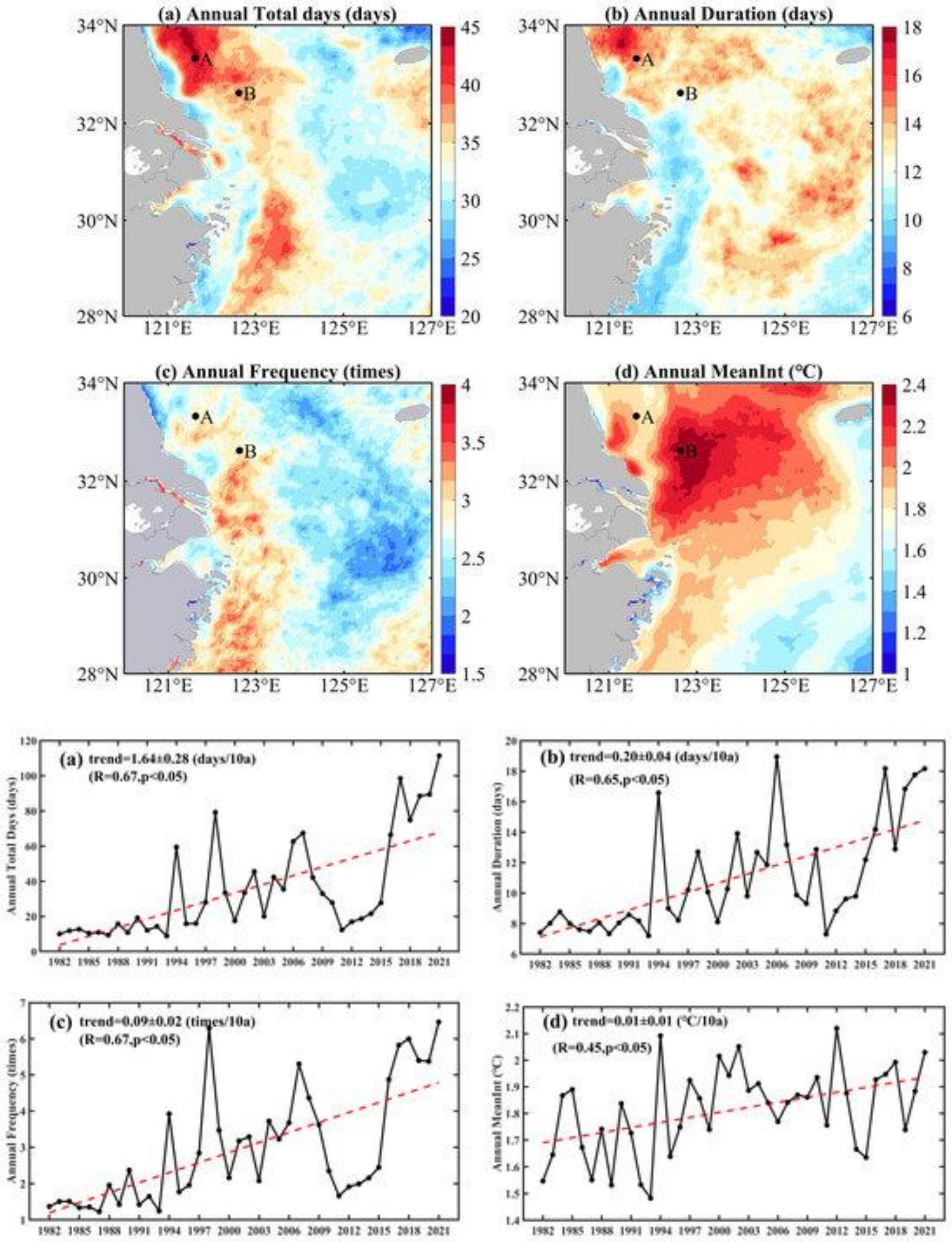
Spatial and Temporal Analysis

Spatial and Temporal Analysis in the Marine Environment refers to the study of marine phenomena concerning their location (spatial) and time (temporal).

Several problems mentioned below are a few examples that can be solved with this type of analysis.

1. **Oil spillage tracking**: Mapping the spread of a spill over time.
2. **Studying Coral Bleaching**: Identifying locations and timelines of bleaching events.
3. **Fish Migration**: Mapping routes and timing of species migration.
4. **Monitoring Human Activities**: Analyzing ship movements or fishing intensity patterns using AIS data over time.

(Amani *et al.* 2022; Haupt *et al.* 2022; Jin *et al.* 2024)



Spatial & Temporal Analysis of Heatwaves
[Taken from: Xie *et al.* 2024]

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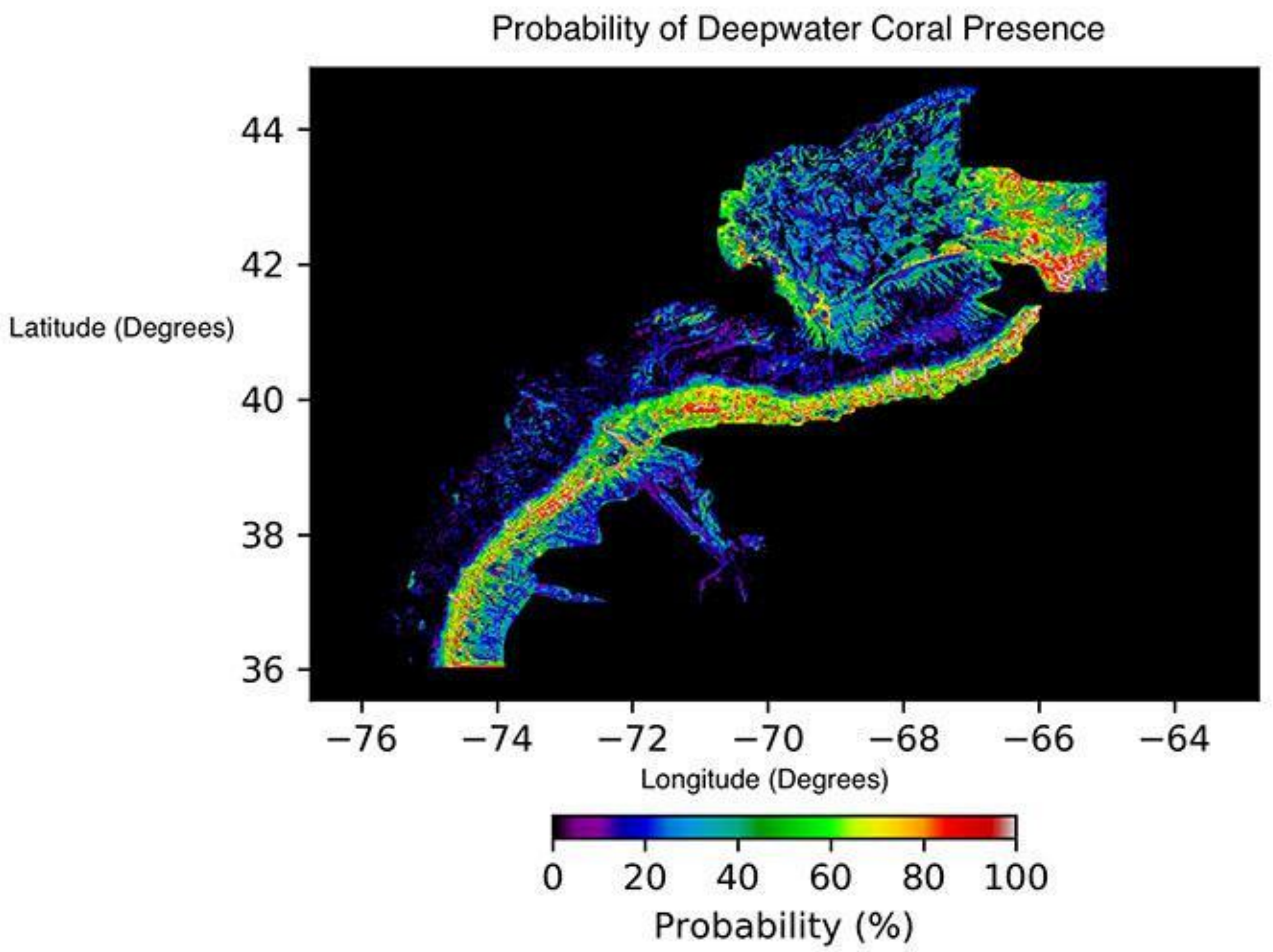
Artificial Intelligence and Modeling

AI (Artificial Intelligence) involves using machine learning (ML), deep learning, and intelligent algorithms to detect patterns, make predictions, or automate analysis, while **modeling** refers to the simulation made using mathematical or computational frameworks. Modelled data are essential for predicting large-scale ocean events and provide a powerful tool for long-term ocean management. Models are vital for environmental forecasting, climate research, and sustainable ocean management. Combined with AI abilities, even more comprehensive models can be created.



Predictive model of deepwater coral presence in U.S.-Canada Atlantic waters
[Taken from: https://oceanexplorer.noaa.gov/okeanos/explorations/ex1905/background/modeling/welcome.html]

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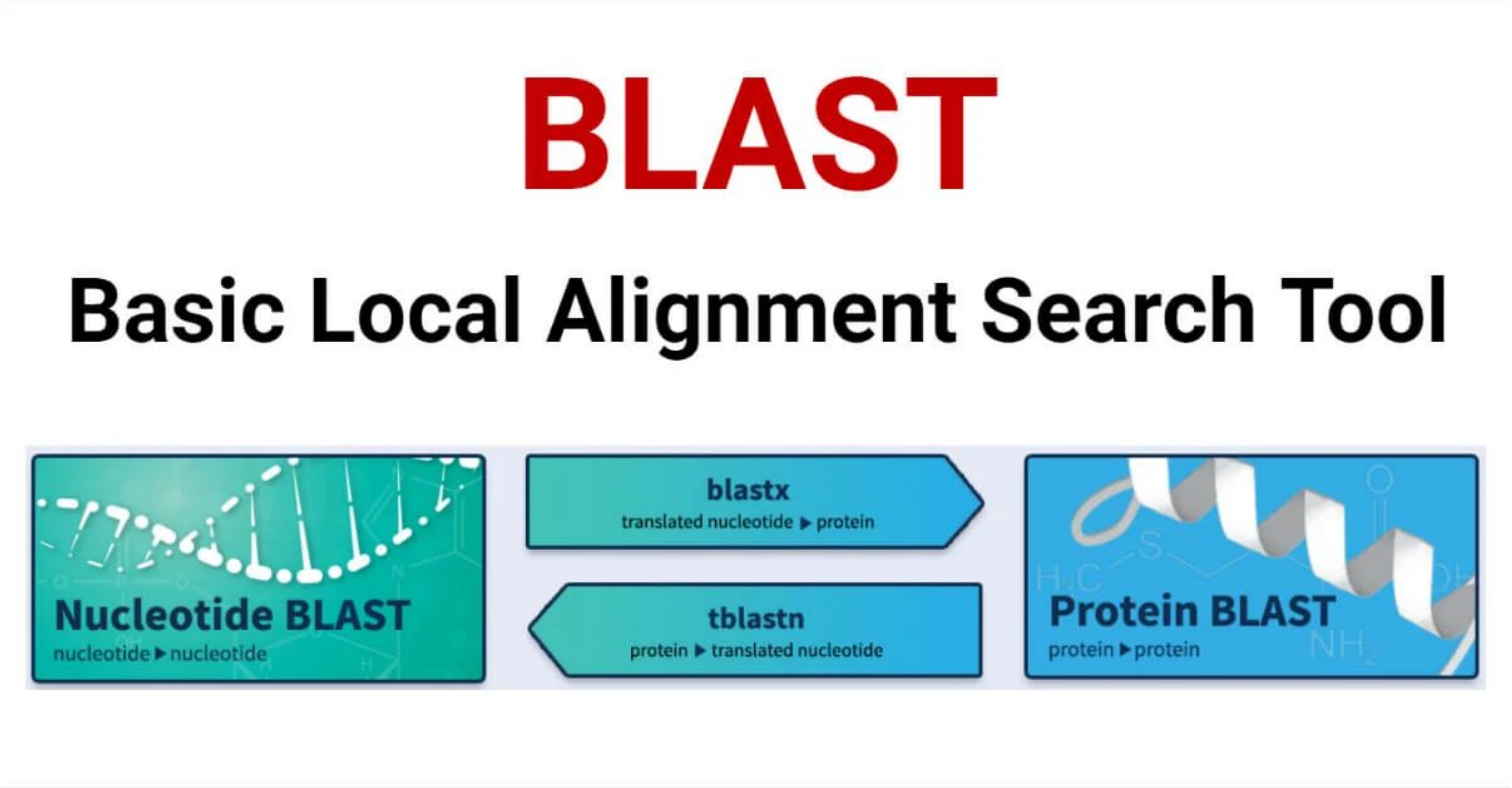
Bioinformatics Tools



Bioinformatics tools function to analyze and interpret biological data such as DNA/RNA sequences obtained from marine organisms.

BLAST (Basic Local Alignment Search Tool)

A bioinformatics tool used to compare biological sequences (DNA, RNA, or protein). It identifies regions of similarity between a query sequence and sequences in a database, calculating the statistical significance of matches.

In marine biology, BLAST is used in genomics research to study the genetic makeup of marine organisms and understand their adaptations and evolution. For example, it can be used to compare the genomes of different coral species or to identify genes involved in stress response in marine animals.

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Marine Digitalization and Biotechnology

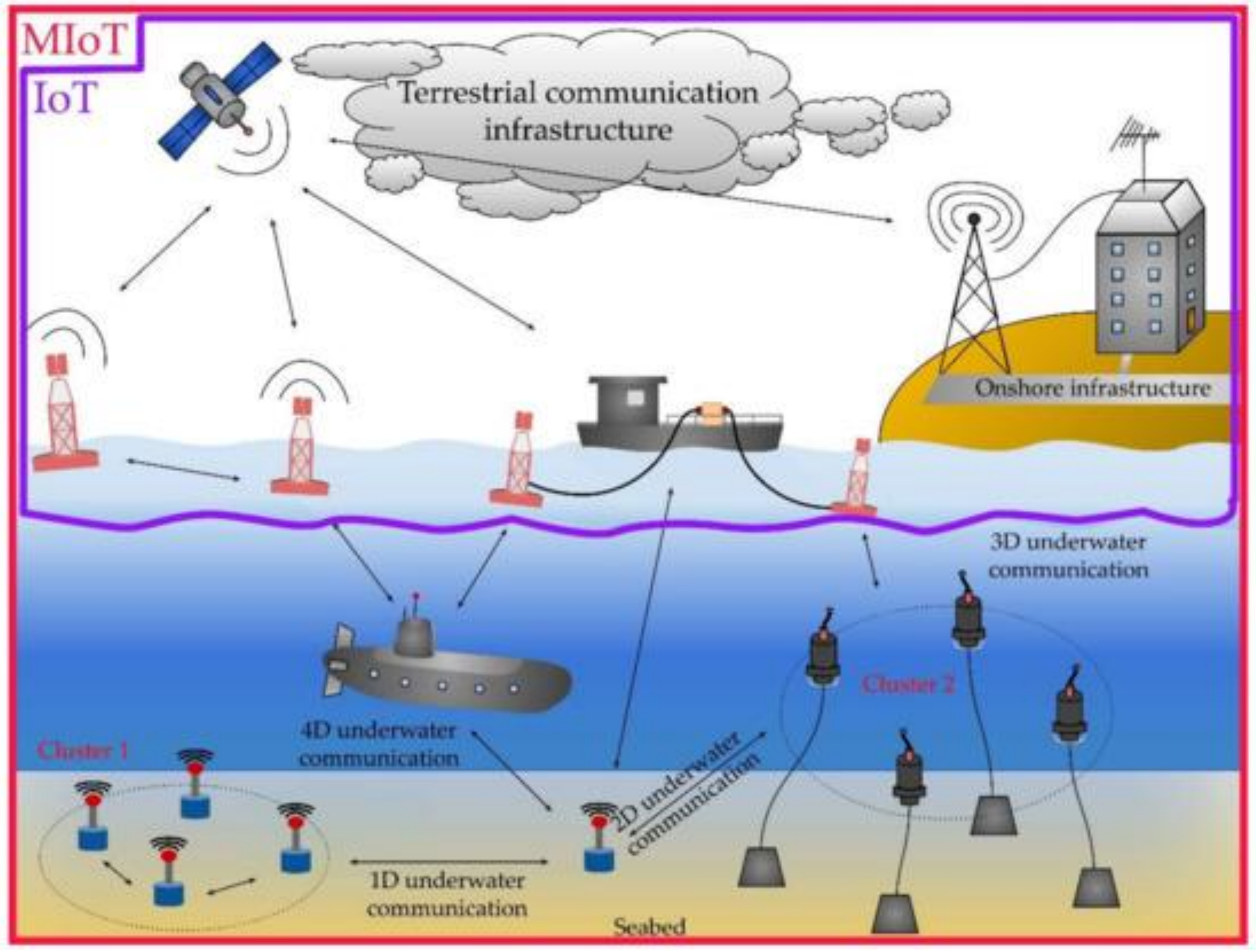
How does digitalization help the advancement of marine biotechnologies?

1. **Sample Procurement**

The genetic diversity of marine bioresources, in particular of marine microbes, provides a wide array of opportunities and challenges for marine biotechnology. It holds significant potential for discovering new bioactive compounds with wide applicability in drugs and in greener, more sustainable industries. However, these bioresources are often difficult to procure since it located deep in the ocean or in areas men cannot reach by themselves.

By utilizing robots, those samples which located in extreme areas may be obtained and can be researched even further.

Marine Digitalization and Biotechnology



[Taken from: Kabanov & Kramar 2022]

2. Internet of Things (IoT): Real-Time Monitoring and Automation

IoT is revolutionizing fisheries by connecting various sensors, devices, and machinery to a centralized network, often monitored and managed through fisheries software. IoT devices used in fisheries include:

- **Environmental Sensors**: These sensors monitor water quality parameters like temperature, pH, and dissolved oxygen in real-time. IoT systems allow for automated adjustments that improve fish health and reduce mortality rates.
- **Smart Feeders**: IoT-enabled feeders can release precise amounts of food based on fish appetite and environmental conditions, managed by fisheries software. This minimizes feed waste, reducing costs and the risk of water pollution.
- **Remote Monitoring**: IoT devices allow fishers and farm managers to monitor operations remotely through software designed for fisheries, making it easier to oversee large fish farms or multiple vessels without physically being present.

(Kabanov & Kramar 2022; Rowan 2023)

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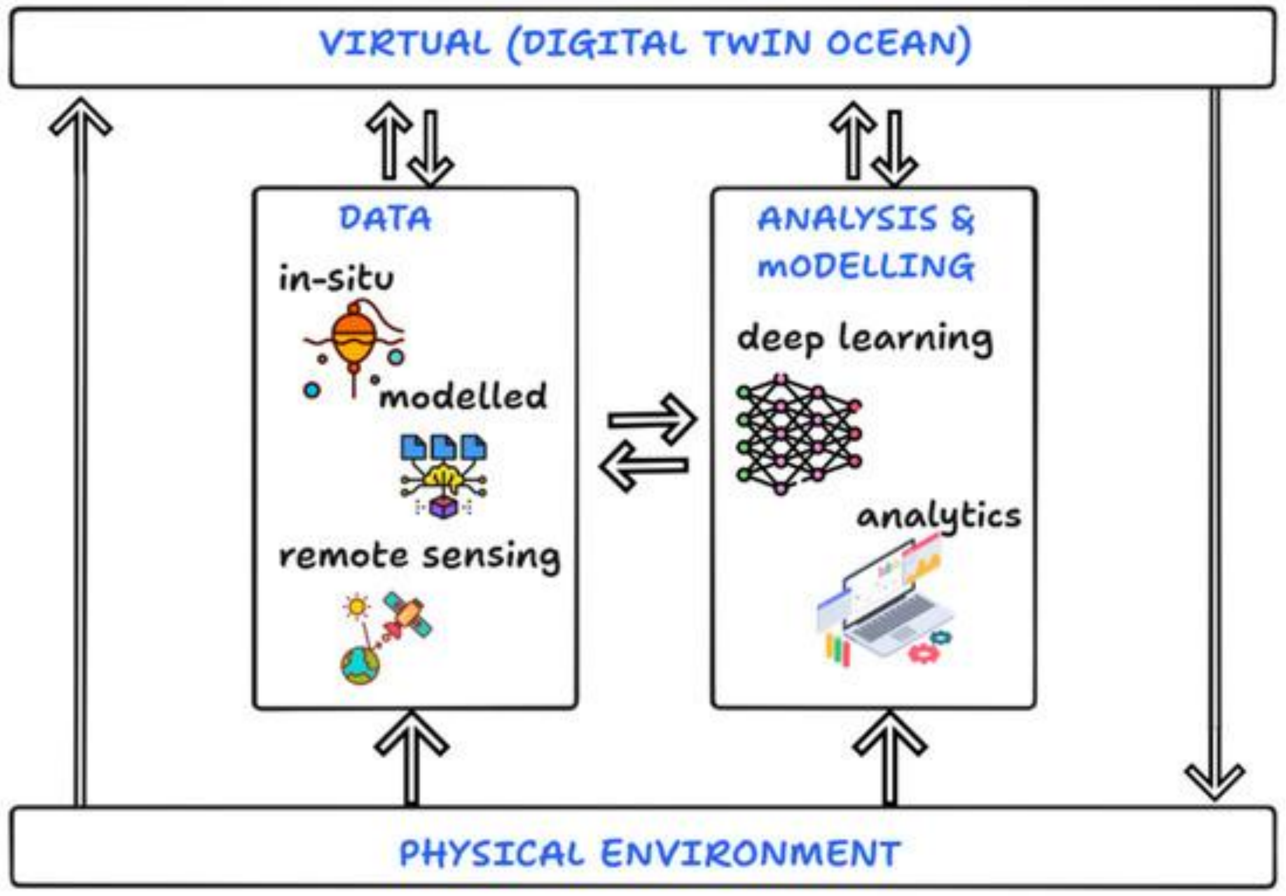
Marine Digitalization and Biotechnology



[Taken from: Haupt *et al.* 2022]

2. Digital Twins of the Ocean (DTOs)

DTOs is a virtual model that simulates and mirrors real-life ocean systems using physical models, sensor data, and computing technologies. DTOs support real-time monitoring and predictive analysis of marine environments throughout their life cycles. Originally introduced as "information mirroring models," digital twins are now widely used, supported by technologies like IoT, AI, deep learning, and cloud computing.

The idea is to create a digital copy of ocean systems so scientists and decision-makers can monitor changes, predict problems (like oil spills), and plan better solutions. These models are built using powerful tools like AI, the Internet of Things (IoT), and cloud computing.

(Haupt *et al.* 2022)

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Geographic Information System (GIS)

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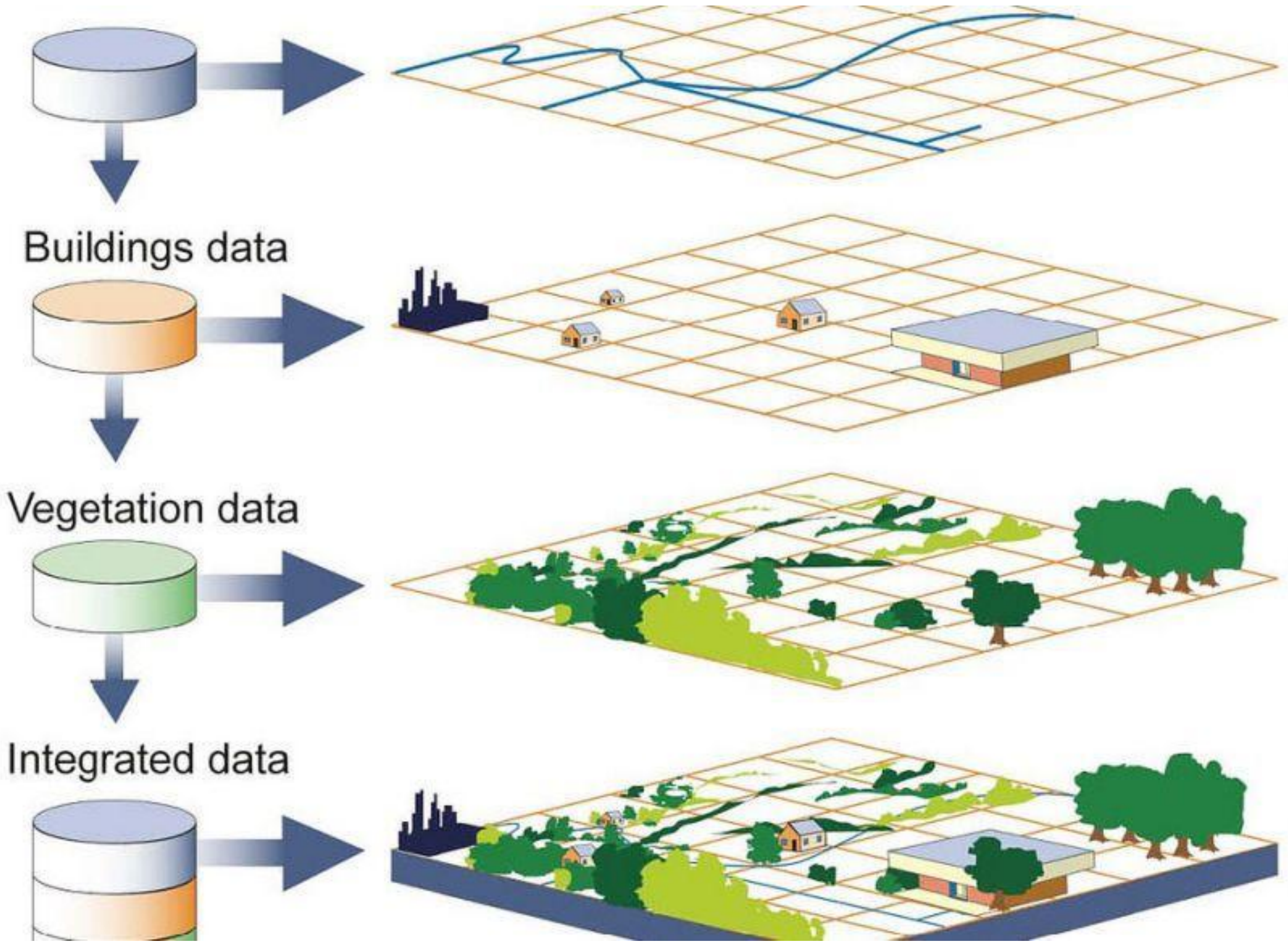
A geographic information system (GIS) is a computer-based conceptual framework used for organizing and analyzing data related to positions on Earth's surface.

The vast and dynamic nature of marine environments presents unique challenges for scientists and researchers, requiring innovative approaches to effectively study and manage these complex ecosystems. GIS addresses these challenges by offering a comprehensive framework to integrate various types of spatial and temporal data, enabling a more holistic understanding of marine systems.

Information based on GIS analysis can increase our understanding of the ocean.



[Taken from: https://education.nationalgeographic.org/resource/geographic-information-system-gis/]

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(https://education.nationalgeographic.org/resource/geographic-information-system-gis/; http://www.inio.ac.ir/en/gisa#:~:text=Mapping%20and%20Monitoring:%20GIS%20is,human%20use%20of%20marine%20resources.)

GIS Function in the Marine Ecosystem

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- **Data Integration and Visualization**: GIS allows for the integration of marine's varied datasets into a single platform, enabling scientists to visualize and analyze complex relationships between physical, chemical, and biological components of marine systems.
- **Mapping and Monitoring**: GIS is critical for mapping marine habitats, monitoring environmental changes, and assessing the impacts of human activities. It helps in creating detailed maps of seafloor topography, coral reefs, and other critical habitats, which are essential for conservation planning and resource management.
- **Spatial Analysis**: The ability to perform spatial analysis using GIS tools helps marine scientists identify patterns and trends. For example, GIS can be used to analyze the distribution of marine species in relation to environmental variables such as temperature, salinity, and depth, providing insights into species' habitat preferences and predicting potential impacts of climate change.

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(https://education.nationalgeographic.org/resource/geographic-information-system-gis/; http://www.inio.ac.ir/en/gisa#:~:text=Mapping%20and%20Monitoring:%20GIS%20is,human%20use%20of%20marine%20resources.)

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Dr. Retno Lestari, M.Si.

retno.lestari@sci.ui.ac.id

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