Coastal Pollution Toolkit

Part 2

Factsheets on

Approaches to Assessing & Monitoring Coastal Pollution

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Factsheets on

Approaches to assessing & monitoring coastal pollution

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Direct, in-situ measurements, observations, & samples

Description

This approach includes water sampling where water samples are taken to a laboratory for analysis, the measurement of water quality parameters in the field with an instrument or testing kit, collection of data through the use of a passive sampler, or the deployment of a data logger to collect data continuously over a set period of time.

When & why to use

This approach is quite versatile and widely used, and there many situations where this approach is recommended as a way to assess pollution:

- To identify the sources of pollution.
- To detect and/or measure concentrations of specific pollutants.
- To determine pollution loads entering aquatic environments (surface, ground, coastal and marine waters).
- To determine the spatial extent and patterns of pollution in aquatic environments.
- To determine whether water bodies comply with water quality criteria and/or standards.
- To determine if an area is safe for contact and/or non-contact recreational activities including swimming.
- To determine if an area is safe for fishing or, aquaculture
- To assess the impact of flood plumes (event sampling).
- To track changes in water quality due to changes in policy, legislation, regulations, management interventions, or land-use.

Personnel requirements & skills needed

Trained personnel are required to undertake sampling and experimental design and data collection, management, analysis, evaluation, and communication. In addition, specialized trained staff may be required to perform laboratory analyses. Personnel should also have ongoing access to training to keep up with latest methods and technologies.

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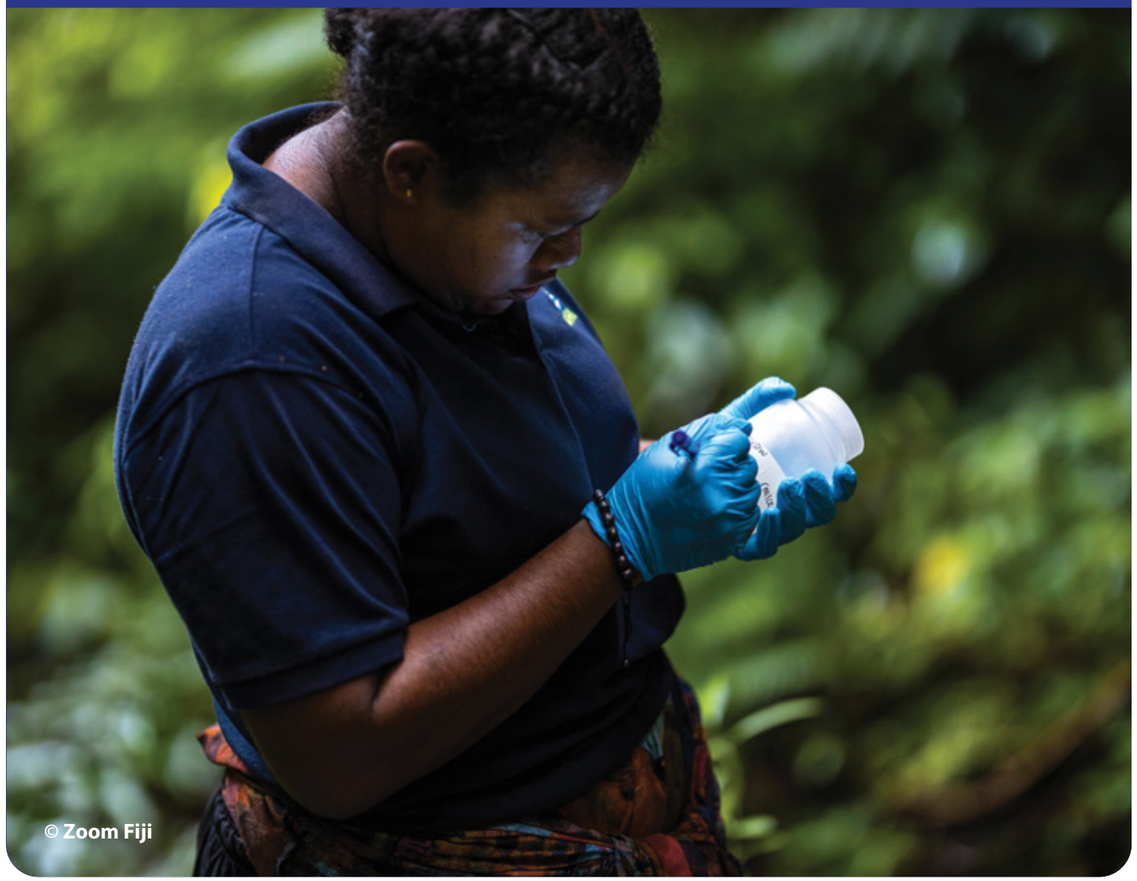
Equipment needed

- Water sampling equipment, including: sample containers, preservatives, reagents, niskin bottles or buckets for water collection, sampling pole (if needed), filters and syringes, personal protective equipment, a cooler, and ice.
- Specialized equipment and instruments, such as: automatic pump samplers (auto-samplers), passive samplers, multi-parameter water quality instruments and sensors, Secchi disk, water testing kits, data loggers, GPS, and boats, fuel, and driver if sampling offshore.
- A laboratory to analyze samples.

Budget requirements

Costs derived from sampling can vary widely depending on several factors, including:

- Size of the area of interest.
- Pollutants of interest.
- Number and distribution of sampling sites.
- Sampling frequency.
- Reagents or preservatives required.
- Transport for sampling and sample retrieval to a laboratory for further analysis.
- The equipment, instruments, sensors, and methods required to detect selected parameters.
- Permits required.
- Costs associated with field work, including land and marine transportation and equipment.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Pros

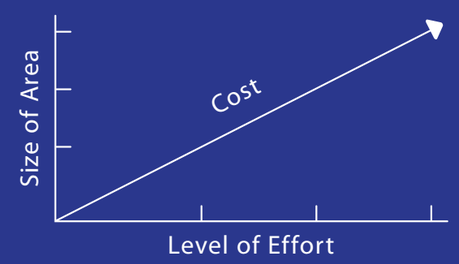
- Provides accurate and precise information about specific pollutants in the water column at the particular point and time when the direct measurement is taken (Cooper et al., 2009; Ritchie et al., 2003; Yang et al., 2022).
- Can measure a wide range of pollutants and water quality parameters.
- Can be incorporated into citizen and community science programs.

Cons

- Can be time-consuming and laborious.
- Subject to fluctuations as tides, winds, currents, temperature, and rainfall patterns vary, making investment into repeated sampling and long-term monitoring critical.
- May require specialized equipment and instruments.
- Expensive for large-scale or frequent discrete sampling.
- Often requires auxiliary information to be collected about the water, such as temperature or salinity, which may require an additional piece of equipment.
- Access to sites for data collection may be restricted.
- Collection and preservation of lab samples require standardized protocols and conditions, such as keeping the sample cold during transport, limited holding times for samples to be analyzed, and access to a certified laboratory in a relatively short distance.
- Challenging to find laboratories to analyze less routinely monitored parameters.
- Certain analyses, such as any involving genetics, can be very expensive.
- Data collected through direct measurements can be extensive and complex, so proper data management will be key.
- Does not adequately predict or reflect the condition of the ecosystem (Gibson et al., 2000; Goonan et al., 2012).

Spatial scale of information

In general, costs will scale linearly with the size of the area of interest and the level of effort (i.e., number of samples, number of sampling sites, and sampling frequency). Due to budget constraints, monitoring is usually conducted on a small spatial scale.



Example questions that can be answered with this approach

- Are water quality standards being exceeded?
- Are there banned substances present?
- Is the source of fecal contamination animal or human?
- Is the water safe for recreational activities?

External resources with more information

- DENR, 2008
- DES, 2018
- Núñez-Vallecillo et al., 2023
- The ASEAN Secretariat, 2008
- US National Office for Harmful Algal Blooms, 2019

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Ecological monitoring of bioindicators

Description

Monitoring of pollution-specific bioindicators can be used to assess the impact of pollution, as they reflect the overall health of ecosystems (Gibson et al., 2000; Zaghloul et al., 2020). They are defined as biological responses that are a) specific towards a driver of change or stressor, b) reflective of the magnitude of any changes, c) consistent across different scales, d) cost-effective, and e) ecologically relevant (Cooper et al., 2009).

Table 1: Examples of common coastal ecosystem pollution bioindicators. Note that this list is not exhaustive nor will all of these bioindicators be appropriate in all places, due to natural variability. We strongly suggest undertaking pilot studies to identify which bioindicators are present in your location. For all of the bioindicators listed below, the higher the prevalence of each one, the more degraded the water quality is

Pollutant Type	Common Parameters for Ecological Monitoring of Coral Reef Bioindicators	What it Can Tell Us About Pollution	References
Sediments	o Coral tissue necrosis o Coral mucus sloughing o Sediment laden turf algae cover o Turf algae length	Sediment can settle on coral, causing the coral polyps to generate mucus to try and remove it, which compromises their health from extra energy use. Eventually, if there is too much sediment, the polyps can die, creating dead patches on colonies that are often covered in sediment. Sediment can settle in turf algae, which suppresses herbivory, causing turf algae to grow. The sediment gets trapped in the algae, and is less likely to be resuspended and cleared from the system. Sediment-laden turf algae can create positive feedback loops that lock coral reefs into a degraded state.	Bessell-Browne et al., 2017; Goatley et al., 2016 Pollock et al., 2014; Tebbett and Bellwood, 2019;
Nutrients and organic matter	o Macrobioeroding organisms o Coral disease o Turf algae cover o Macroalgae cover o Benthic cover of cyanobacterial mats o Zoanthid cover o Percentage of epiphyte cover on seagrass o Percentage of dead leaves in seagrass meadows	Nutrient enrichment and increases in organic matter can result in the proliferation of turf algae, macroalgae, macrobioeroding organisms, epiphytes, and zoanthids. Increases in nutrients can also create conditions that are more favorable for microorganisms to proliferate, causing coral disease. Increases in nutrients as well as changing ratios of nitrogen and phosphorus can cause benthic cyanobacterial mats to proliferate. Changes in reef benthic composition and increases in epiphytes on seagrass can create positive feedback loops that lock the ecosystems into degraded states.	Bruno et al., 2003; Cooper et al., 2008; Fabricius et al., 2012; Ford et al., 2017, 2018; Le Grand and Fabricius, 2011; Lamb et al., 2016; Larsen et al., 2023; McClanahan et al., 2007; Vaughan et al., 2021

When & why to use

Monitoring of bioindicators should be conducted when trying to assess the impact of pollution on ecosystems or to track changes in ecosystem health in response to management of pollution. They are more sensitive to pollution than other metrics of ecosystem state, and therefore are a better early warning indicator of a problem or an early indication that pollution levels are reducing in response to management (**Table 1**).

Personnel requirements & skills needed

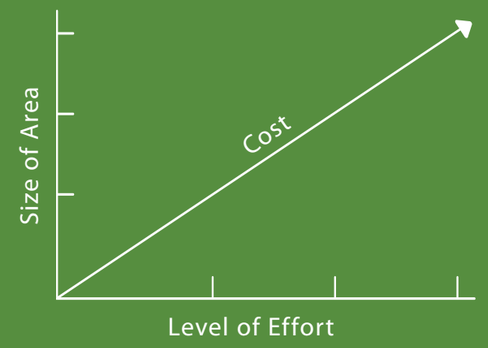
The level of taxonomic specialization and level of expertise required will depend on the methods used. When genus or species-level identification is necessary, compared to higher taxonomic levels, a well-trained taxonomist would be required (Gibson et al., 2000). Otherwise, someone trained in monitoring and evaluation of the ecosystem of interest should be able to conduct bioindicator monitoring with the appropriate training. In addition, trained personnel will be required to analyze data to detect patterns over space and/or time.

Equipment needed

The equipment needed will depend on the ecosystem being sampled, but will generally involve transportation to reach the field site, GPS, a transect tape or quadrats, a notebook or slate to record data, snorkel or SCUBA equipment if relevant, and a computer to store and analyze data.

Budget requirements

- Trained staff, plus training activities if needed. Most field sampling will require multiple staff to meet workplace safety regulations.
- Costs associated with field work, including transportation and equipment.
- Equipment requirements as detailed above.



Spatial scale of information

In general, costs will scale with the number of days of fieldwork required and whether monitoring is conducted from a liveaboard vessel or from daily trips from shore. There, the total budget and monitoring logistics will dictate the spatial scale at which data can be collected.

Example questions that could be answered with this approach

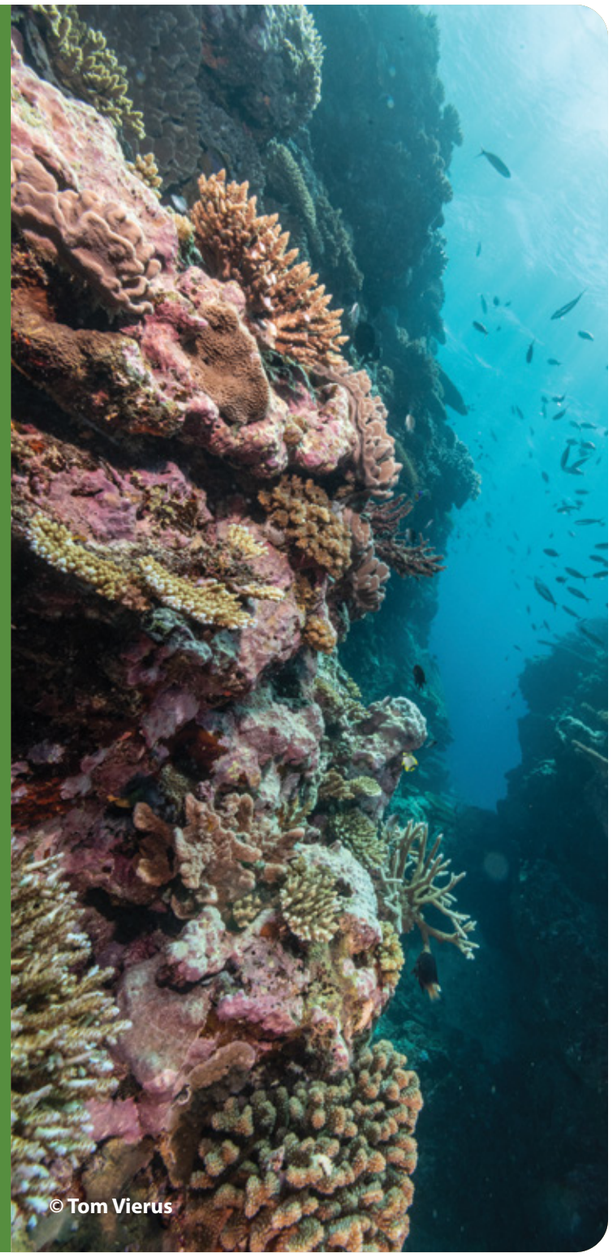
- Are there detectable adverse impacts of pollution on ecosystem condition?
- Have management interventions resulted in changes to the ecosystem state?

Pros

- Provides information on biological and ecological responses to pollution.
- A more stable indicator of pollution than discrete water samples.
- Reflects the cumulative effects of disturbances and is useful to assess the severity of impacts.
- Complements water quality data, by reflecting the cumulative impacts of human activities and disturbances in the biota of a waterbody.

Cons

- Pollution bioindicators vary with locations meaning that not all bioindicators will be relevant in different contexts. Pilot studies may be required to identify the most appropriate bioindicators.
- Not all species in the community will have the same type or severity of response to pollutants (Zaghloul et al., 2020).
- Cannot be used to differentiate between sources of pollution.
- Not all pollutant types have a clear bioindicator, limiting this approach to a subset of pollutant types.
- Complex and can be time-consuming and costly.
- Bioindicators are affected by other factors not related to pollutants, such as temperature, disease, parasitism, competition, or predation, which can confound interpretation of results.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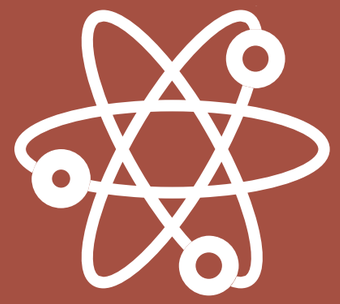
External resources with more information

- Coleman & Cook, 2007
- Gibson et al., 2000
- U.S. EPA, 2008

Biotic & abiotic sampling for further assessments



Description

The collection of organisms, organism components, or sediments to assess 1) the bioaccumulation of a pollutant within the tissue or skeletal material of an organism; 2) physiological and anatomical abnormalities or deformities; 3) changes in a system through time; and 4) sources of pollutants. **Unlike the ecological monitoring of bioindicators, this sampling approach requires samples to be collected and further analyzed in a laboratory with specialized equipment**.

When & why to use

The collection of organisms can be used to detect pollution exposure or impacts on biota at cellular, biochemical, or biological scale (Shahid et al., 2022). The collection of sediments or the preserved remains of organisms can provide a long-term record of pollution input (Duprey et al., 2019). This approach can provide an array of information on how pollution has changed over time and/or space and is influencing a system, which may not be otherwise apparent through routine ecological monitoring (**Table 2**).

Table 2: An example of different assessments that can be conducted on collected organisms or sediments that can help to understand water pollution impacts. Note that this list is not exhaustive

Collection Type	Type of Assessment	What it Can Tell us About Pollution	Additional Information & Resources
Organism tissue	Bioaccumulation of pollutants	Concentration of pollutants within the tissue of marine species can identify if they have accumulated to unsafe levels for human consumption or population viability.	Fabbri and Franzellitti, 2016; Madikizela and Ncube, 2022; Nalley et al., 2023
Organism tissue or skeleton; coral core	Stable isotope analysis	^{15}N:^{14}N stable isotope analysis can help differentiate if the source of nitrogen pollution is agricultural runoff or domestic wastewater. Stable isotope analysis along the length of a coral core can indicate how sources of nitrogen pollution have changed through time.	DES, 2018; Duprey et al., 2019; Risk et al., 2009

Collection Type	Type of Assessment	What it Can Tell us About Pollution	Additional Information and Resources
Whole organism	Histological assessment	Quantify the incidence of pathological tissue changes in the main organs. Assessment of gills or liver can tell us about biological impacts occurring within organisms that may not be detectable with ecological monitoring.	Corbett et al., 2014; Schlacher et al., 2007; Shahid et al., 2022
Whole organism or sediment core	Accumulation of microplastics	Accumulation of microplastics within organisms or sediment cores can provide information on microplastic hotspots and the risk to humans of microplastic ingestion from particular fisheries species.	Haave et al., 2021; Hennicke et al., 2021; Littman et al., 2020
Whole organism or tissue	Genetic analysis of microorganisms	Genetic analyses can be used to identify the presence and prevalence of microorganisms within an organism, which can be used to indicate exposure to different pollution sources, identify drivers of disease, or determine the risk to humans from consumption of contaminated fisheries species.	Razafimahefa et al., 2019; Sutherland et al., 2010; WHO, 2010
Coral skeleton	Linear extension rates and density measurements	Linear extension and density measurements of annual growth bands in coral skeletons provide estimates of whether colony growth rate differs in polluted water compared to unpolluted water.	Browne et al., 2015; Thompson, 2021
Whole organism or tissue	Biomarkers	Biomarkers are the biological responses elicited from exposure to pollutants. They can be used to detect molecular and cellular changes in organisms prior to noticeable responses at the individual or population level. They are especially useful in detecting impacts from persistent organic pollutants, which cannot be reliably assessed through ecological monitoring of bioindicators.	Kadim and Risjani, 2022; Sarkar et al., 2006
Sediment samples or cores	Foraminifera assemblage assessment (FoRAM Index)	Foraminifera have short life spans and respond quickly to environmental change. In reef environments, nutrient enrichment and increases in organic matter can change the assemblages in consistent and predictable ways, making them an important bioindicator for both recent and historic changes in water quality.	Narayan et al., 2022; Prazeres et al., 2020

Personnel requirements & skills needed

- Trained technicians to collect, preserve, and transport samples.
- Specialized trained staff to perform laboratory analyses.
- Trained personnel to analyze and interpret data.

Equipment needed

Sampling equipment; preservatives and reagents; sample containers; coring device (push core for sediment core or pneumatic drill outfitted with core barrel and powered by air compressor for coral core); snorkeling or SCUBA equipment; access to laboratories that can conduct stable isotope, genetic, or tissue analyses; x-ray machines for detecting coral annual growth bands from coral cores; computer and software for analyzing coral annual growth bands or bioinformatics following genetic analyses.

Budget requirements

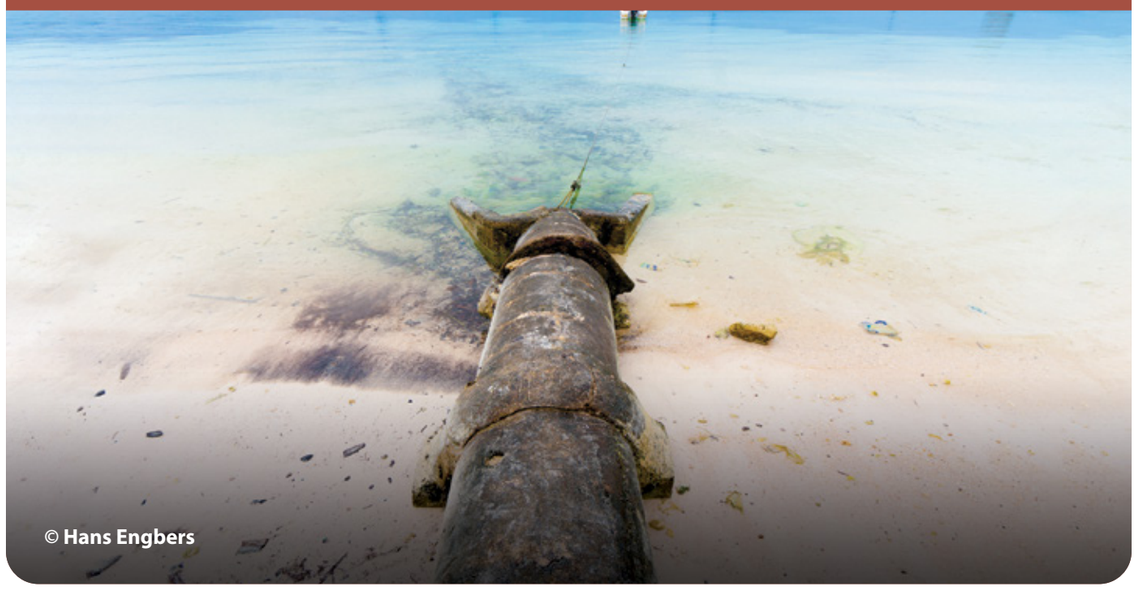
Specialized trained staff; snorkel or scuba diving training; equipment for sample or organism collection; costs associated with field work, including transportation and equipment; collection permits, fees for sample analyses; costs for laboratory analyses.

Spatial scale of information

Due to budget constraints, it usually is conducted on a small spatial scalect.

Example questions

- Are there detectable adverse impacts of pollution on ecosystem condition?
- Have management interventions resulted in changes to the ecosystem state?:
- Are there detectable adverse biological/ physiological impacts on species?
- Is the nitrogen source predominantly from sewage or agriculture? (in-situ collection of biological or geological samples for stable isotope analysis)
- Are pollutants accumulating to unsafe levels in biota consumed by people?
- Have adverse impacts from pollution changed over time? (in-situ collection of biological / geological samples - sediment or coral cores)
- How are changes in coastal water quality related to land use and land cover change?



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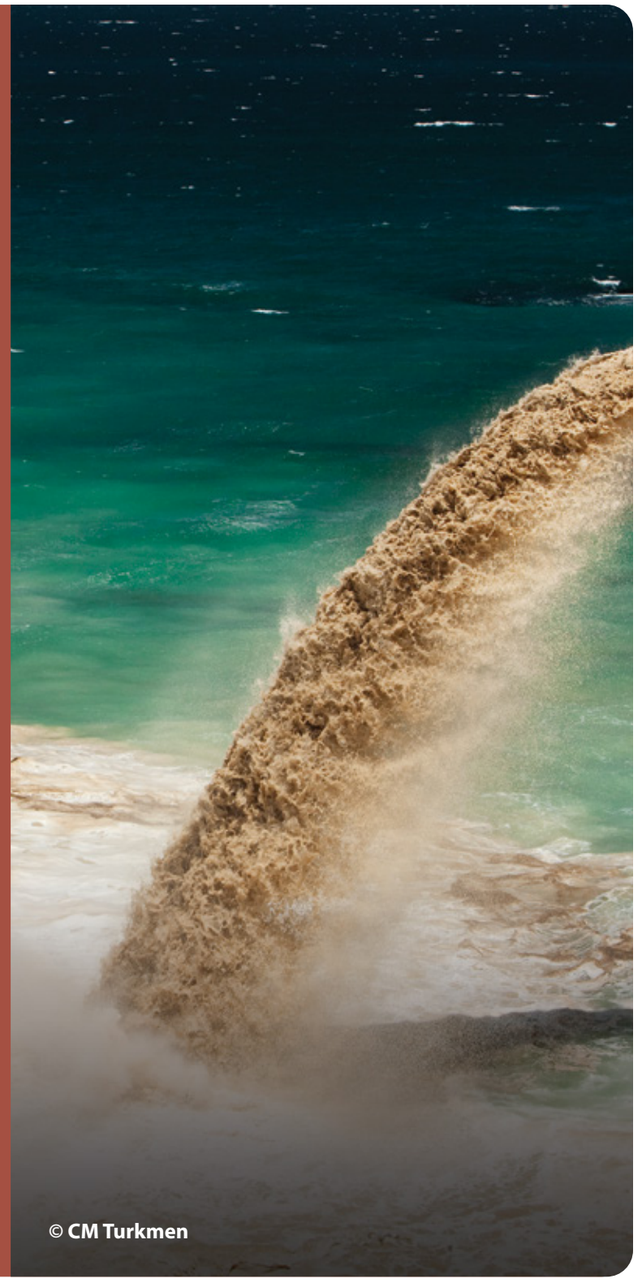
Pros

- Detailed information on biological and chemical interactions.
- Coring can allow for reconstructions of long-term patterns of pollution in the absence of monitoring efforts, from decadal to millennial time-scales.
- Provides information on the direct and indirect effects on organism physiology and biology, which may not be apparent through ecological monitoring.
- Can act as an indicator of an organism's population health in the ecosystem.
- Can provide important information on the safety of fisheries species for consumption.
- Can be an early warning indicator of impacts from pollution.

Cons

- Higher-level of expertise required for sample collection, preservation, and analysis than for routine ecological monitoring.
- Requires specialized equipment for analyses.
- Analyses are expensive.
- Time-consuming and laborious analyses.
- Limited spatial and temporal information (with the exception of coring for temporal scale of information).
- Expensive for large-scale assessment.
- Complex data analysis and interpretation.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External resources with more information

- Dardeau et al., 2004
- NOAA, 2023
- Reichelt-Brushett et al., 2023

Quantitative modeling

Description

Quantitative models such as pollutant transport models, hydrodynamic models, statistical models, or mechanistic models provide a transparent and repeatable way to investigate connections and relationships within systems and to inform decision-making management and development. They can be used to assess the extent and magnitude of a pollution problem; to provide insights into the dynamics of complex connections between the sources of pollution and the impacts on ecosystems; and to evaluate the efficacy of proposed management interventions or proposed development.

When & why to use

Models can be used to quantify the amount of a pollutant that is likely to reach the coast and its main sources; map the dispersal of pollutants within coastal and marine environments; understand the relationship between pollutants and ecosystems; and make predictions about how changes in land-use or management will influence these factors.

Personnel requirements & skills needed

A person with a high degree of expertise in spatial analysis, environmental science, and coding is required to develop and perform quantitative modeling.

Equipment needed

A computer capable of efficient data processing and datasets to create and parameterize models.

Budget requirements

Specialized trained staff; high spec computers; data acquisition; field visits for model calibration.

Pros

- Allows for forecasting and hindcasting of changes.
- Very useful to inform decision-making on management or development.
- Can provide information on pollutant transport, fate, and behavior.
- Can simulate ecosystems' responses to stressors and hydrodynamic behavior of flows.
- Can be used for much larger spatial scales, so is very cost effective compared to other approaches listed above.
- Can be used in data-limited environments.
- Can establish a relationship between pollution and ecosystems.

Cons

- Longer time frames required to develop and parameterize models.
- Can be difficult to find local datasets for models.
- There are trade-offs between the spatial-scale at which models can be run and the availability and comparability of datasets available.
- Requires up to date and reliable data to be very accurate.
- Lack of validation with in-situ data can impact the reliability of the results.
- There can be a high uncertainty in results due to assumptions about relationships and system responses required during model development.

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Spatial scale of information

- Models can be developed for local to global spatial scales, but the desired spatial scale will have implications for processing times and data availability.

Example questions

- What are the current pollution loads in the area?
- What are the main sources of pollution in the watershed?
- Are there erosion hotspots?
- Which areas are most polluted?
- Have management interventions changed pollution loads?
- How will pollution loads change in the future based on current trends?
- How far can pollution spread in the marine environment?
- Will climate change effects influence rates of pollution in the watershed?
- Have management interventions changed pollution dispersal?

External resources with more information

- Stanford University, n.d.
- SWAT, n.d.

Remote sensing with satellite data

Description

Satellite data can be used to track and quantify turbidity and algal blooms in watersheds and coastal environments on a fine spatial scale. This can be as simple as utilizing images from Google Earth or using a drone, and it can be more complicated by either downloading or paying for satellite data from government agencies or paid providers. Advanced analyses can help to determine the scale of the impact. Satellite images can be used following storms to determine the extent of pollution plumes. Often historical satellite data is available so that a comparison can be made.

When & why to use

- To investigate sources of erosion.
- To look for algal blooms.
- To track turbidity or poor water clarity in the nearshore waters.
- To track changes in land-use, for instance vegetation changes, impacts from fire, or new development.
- To detect and track large-scale pollution events and impacts such as sewage plumes, oil spills, and harmful algal blooms (Callejas, 2022).

Personnel requirements & skills needed

There is a range of expertise required, depending on how remote sensing will be used. First pass analyses can be done by most with adequate training, while a well-trained analyst is needed to process satellite imagery using advanced analyses.

Budget requirements

- Highly qualified analyst.
- Computer equipment with high-processing and storage capacities.
- GIS software or cloud/online storage and processing services.
- Potential costs associated with acquiring high-resolution or specialized satellite data.

Equipment needed

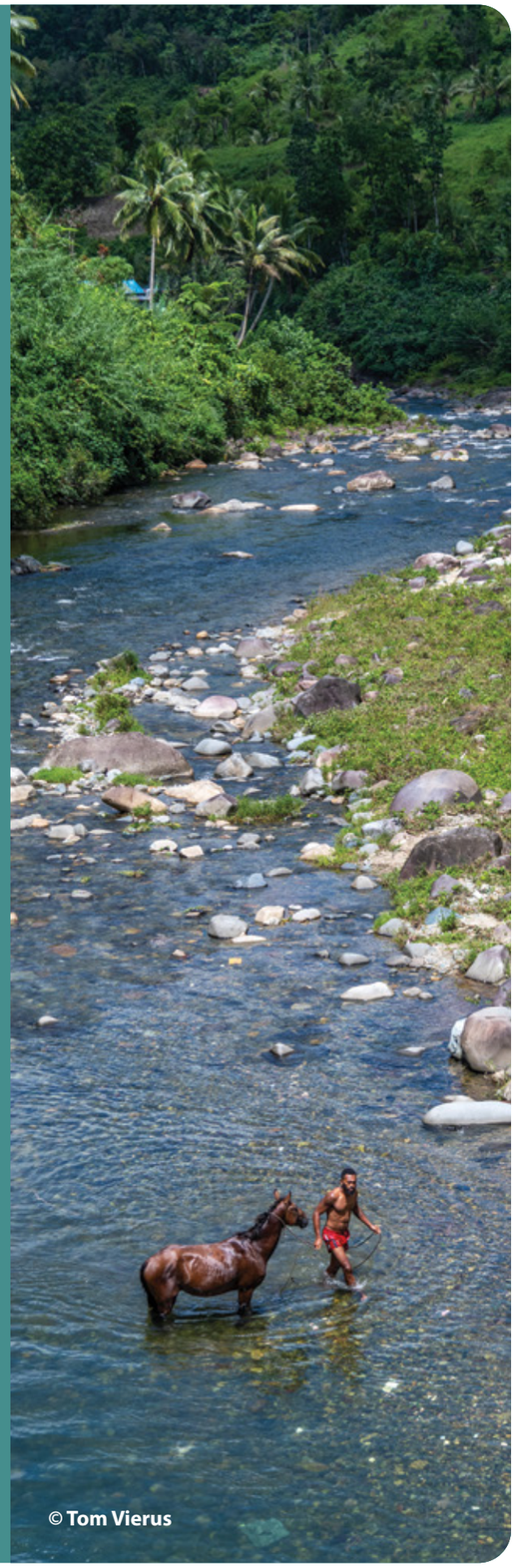
- Computer equipment with high-processing and storage capacities.
- GIS software or cloud/online storage and processing services.
- Alternatively, some datasets like Landsat or Sentinel-2 are freely accessible and can be processed online in Google Earth Engine for free.

Pros

- There can be high temporal frequency in new data (i.e., a new satellite image every week), depending on the product used.
- Data available in digital form, therefore is easily readable for computer processing.
- High spatial and temporal coverage.
- Cost effective for large scale data gathering.
- Effective for areas with limited in-situ data available.
- Lots of available resources.
- Useful for areas with limited access.
- Potential for correlations between water column reflection and optical active components, such as transparency, chlorophyll-*a* concentration (phytoplankton), organic matter, and suspended sediments.
- Suitable for optical parameters in surface waters.

Cons

- Hard to analyze imagery when there is a cloudy system, which is also when water quality may be impaired.
- Very high-resolution satellite imagery is less freely available.
- If partnerships are not in place, access to imagery can be very expensive.
- There are only a few depths where the technique is optimal - too shallow or too deep and the information is limited.
- Difficulty to compare outcomes due to lack of a standardization system, and lack of validation data can impact on the reliability of the results.
- Some studies have reported inaccurate results due to the interference caused by the presence of suspended material in turbid water bodies, especially close to coasts where there are shallow ecosystems.
- Most pollutants do not change the spectral or thermal characteristics of surface water, making it difficult to use remote sensing to directly measure them (Ritchie et al., 2003).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Example questions that could be answered with this approach

- What are the main sources of pollution in the watershed?
- What is the spatial extent of pollution?
- Which areas are most polluted?
- What is the natural variability of water pollution in time and space?
- Has land-use changed over time?

Spatial scale of information

Remote sensing and spatial analysis can be conducted at local to global spatial scales, but the desired spatial scale will have implications for processing times and data availability. Additionally, resolution can vary, affecting the level of detail that can be discerned.

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External resources with more information

- Devlin et al., 2023
- Earth Lab, 2017
- Gholizadeh et al., 2016
- NOAA, n.d.
- Yang et al., 2022

Indigenous & local knowledge

Description

Dynamic bodies of integrated, holistic, social and ecological knowledge, practices, and beliefs pertaining to the relationship of living beings, including people, with one another and with their environments. Indigenous and local knowledge is grounded in place, is highly diverse, and is continuously evolving through the interaction of experiences, innovations and various types of knowledge (written, oral, visual, tacit, gendered, practical and scientific). Such knowledge can provide information, methods, theory and practice for sustainable ecosystem management (Burgos-Ayala et al., 2020; IPBES, 2017)).

When & why to use

This rich source of information can provide important insights into changes in the environment and resources over long time frames, as well as observed patterns, drivers, pathways, and impacts of pollution. It is an important source of long-term historical perspectives and temporal understanding of change and impacts. Indigenous Peoples have long-standing relationships with their surrounding environment, and their expertise and place-based stewardship practices should be elevated as critical components of any sustainable management plan.

Personnel requirements & skills needed

- Flexibility, versatility and adaptability to listen to and understand people's ideas, perspectives, beliefs, and cosmovision (Alexander et al., 2019).
- Training in participatory and cross-cultural approaches (Alexander et al., 2019).
- Fluency in the local language where relevant.
- Ability to manage tensions and disagreements during communication and data collection (Alexander et al., 2019).

Inputs

- Time investment to build positive and trusting relationships between communities and external staff collecting data (Alexander et al., 2019), and engagement of local community members as project staff.
- Be prepared with a range of communication and data collection methods to use depending on knowledge needs and people preferences to communicate (Alexander et al., 2019).

Budget requirements

Staff trained in community and Indigenous engagement; interpreters; travel costs.

Equipment needed

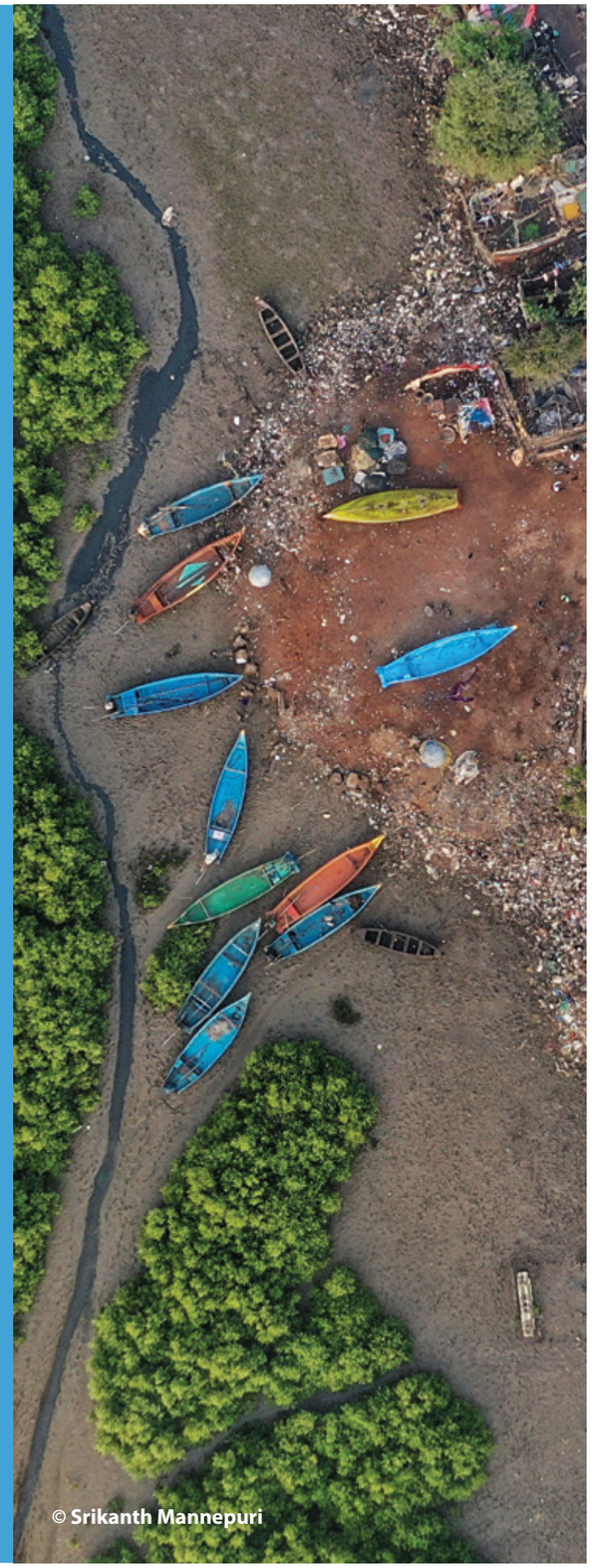
Voice recorder, video camera, GPS, and other specific equipment depending on the knowledge needs, paper, and markers.

Pros

- Significant intimate and specialized knowledge with the environment (Pearson & Gorman, 2023).
- Historical knowledge can provide information on decadal changes.
- Plays an important role in evidence-based decision making and environmental management (Alexander et al., 2019).
- Can significantly facilitate the inclusion of local actors and decision-makers in both the monitoring process and the interpretation of results, thereby fostering a more collaborative and inclusive approach to environmental management.

Cons

- Language barriers.
- Limited time of local people to participate due to community commitments/obligations (Thompson et al., 2020)
- Research fatigue of communities due to their participation in other projects (Thompson et al., 2020)
- Building trust can be difficult due to the perception that monitoring data can be used against Indigenous Peoples and local communities, given historical and contemporary power imbalances and breaches of trust (Thompson et al., 2020).
- Difficulties in keeping people engaged over long-periods of time, if needed (Thompson et al., 2020)
- Difficulties in maintaining funding for data collection in the long-term (Thompson et al., 2020).
- Some data is sensitive and cannot be shared with large audiences (Thompson et al., 2020).



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Important considerations

- Free, prior, and informed consent must be given prior to participation in a project and any data collection.
- Results of projects must be communicated back to participants and communities in an accessible manner (Thompson et al., 2020).
- Project results must be reviewed with communities prior to broader dissemination.
- Define from the beginning data ownership and intellectual property rights (Thompson et al., 2020).

Spatial scale of information

Limited to people's area of knowledge and interaction.

Example questions that could be answered with this approach

- What were the historical water quality conditions prior to intensive land change, agriculture, etc?
- Are there erosion hotspots?
- Which areas are most polluted?
- How far can pollution spread?
- Is the water safe for aquaculture, fishing, or recreational activities?
- What is the natural variability of water pollution in time and space?
- Are there detectable adverse impacts on ecosystem or species condition, e.g., fish kills, algal blooms?
- What practices have been implemented previously to reduce pollution?
- Have management interventions or land-use changed pollution loads?
- Have management interventions or land-use changed pollution dispersal?

External resources with more information

- Kaiser et al., 2019
- Thompson et al., 2020
- Tsatsaros et al., 2020

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