

Citizen Science and Community-Based Monitoring

Provides guidance on incorporating citizen science and community-based monitoring data into ocean accounts.

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OUTCOME

This Circular provides guidance on incorporating citizen science and community-based monitoring data into ocean accounts, with particular attention to quality assurance for non-official data sources and compilation procedures for integrating volunteer-collected data with official statistics. Readers will gain an understanding of the types of marine citizen science programmes that can generate useful data for ocean accounting, the quality considerations that must be addressed when working with such data, approaches for integrating non-official data sources with official statistics, and concrete compilation procedures for processing citizen science observations into account-ready datasets. The guidance recognises that methods for incorporating citizen science data into official statistics are still developing, and standards in this area continue to evolve. Given this Emerging status, compilers should exercise appropriate caution when incorporating citizen science data into ocean accounts, clearly document the data sources and quality considerations, and be prepared to update approaches as methodological standards evolve.

Where relevant, this Circular identifies connections with traditional and indigenous knowledge systems, though the detailed treatment of these knowledge systems is provided in [TG-3.6 Traditional Knowledge](#). Given the relevance of citizen science data to ecosystem condition monitoring, familiarity with ecosystem accounting concepts from [TG-3.3 Economic Activity Relevant to the Ocean](#) is recommended. The quality assurance framework applicable to all ocean accounting data, including citizen science contributions, is established in [TG-0.7 Quality Assurance Principles](#). Key terms used in this Circular are defined in [TG-0.6 Glossary of Key Terms](#). Indicators derived from citizen science monitoring programs may support the indicator frameworks described in [TG-2.1 Aggregate Biophysical Indicators of Environmental State](#).

Citizen science data may contribute to multiple account types within the ocean accounting framework. [TG-3.5 Social Accounts](#) addresses the broader framework for social accounts, including community wellbeing and participatory assessment. [TG-6.12 Marine Litter and Plastics Accounting](#) specifically addresses beach litter surveys conducted by volunteer groups as a source for marine pollution accounts.

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ABOUT THIS CIRCULAR

RECOMMENDED CITATION

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<https://guidance.oceanaccounts.org/circulars/section-4/4-4-citizen-science/>

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DRAFT

¶1 ⓘ Framework Position

¶2 TG-4.4 sits within Section 4 (Data Methods). It owns the treatment of volunteer-collected observations as a statistical source: programme typology, tier assignment, bias assessment and calibration against official data, FPIC and CARE governance for community-based monitoring, and the provenance and uncertainty that must travel with every citizen science estimate. It does not own the accounts those estimates feed. Ecosystem extent and condition accounts are **TG-3.1 Asset Accounts** Sections 3.5.1–3.5.2; marine litter stock accounts are **TG-6.12 Marine Litter and Plastics Accounting**.

1. Outcome

¶1 This Circular provides guidance on incorporating citizen science and community-based monitoring data into ocean accounts, with particular attention to quality assurance for non-official data sources and compilation procedures for integrating volunteer-collected data with official statistics. Readers will gain an understanding of the types of marine citizen science programmes that can generate useful data for ocean accounting, the quality considerations that must be addressed when working with such data, approaches for integrating non-official data sources with official statistics, and concrete compilation procedures for processing citizen science observations into account-ready datasets. The guidance recognises that methods for incorporating citizen science data into official statistics are still developing, and standards in this area continue to evolve. Given this Emerging status, compilers should exercise appropriate caution when incorporating citizen science data into ocean accounts, clearly document the data sources and quality considerations, and be prepared to update approaches as methodological standards evolve.

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¶3 Citizen science data may contribute to multiple account types within the ocean accounting framework. **TG-3.5 Social Accounts** addresses the broader framework for social accounts, including community wellbeing and participatory assessment. **TG-6.12 Marine Litter and Plastics Accounting** specifically addresses beach litter surveys conducted by volunteer groups as a source for marine pollution accounts.

2. Requirements

¶1 This Circular requires familiarity with:

- ¶2 **TG-0.1 General Introduction to Ocean Accounts** – provides foundational understanding of Ocean Accounts components and the relationship between environmental and economic accounting frameworks.
- ¶3 **TG-0.7 Quality Assurance Principles** – establishes the general quality framework applicable to ocean accounting data, including the quality dimensions and metadata standards that must be applied when assessing fitness for purpose of citizen science contributions.
- ¶4

TG-3.1 Asset Accounts – for the ecosystem condition and extent accounting frameworks to which citizen science data on marine biodiversity and habitat condition can contribute, including the biophysical indicators and tiered measurement approaches referenced in this Circular.

3. Guidance Material

¶1 The *Framework for the Development of Environment Statistics* (FDES 2013) recognises that environment statistics draw upon diverse data sources, including “scientific research and special projects undertaken to fulfil domestic or international demand”¹. In the marine context, citizen science programmes can provide observations on coastal conditions, marine species distributions, and environmental quality that may complement or extend official data collection in contexts where official monitoring networks have limited spatial or temporal coverage.

¶2 Integrating citizen science data into official statistical frameworks involves substantial methodological considerations. The *SEEA Ecosystem Accounting* (SEEA EA) emphasises that “appropriate review and validation of the data will be required, including, for example, consideration of the various measurement concepts and scopes that have been applied, to ensure that the data are suitable for the purposes of ecosystem accounting and that coherence across the accounts can be achieved”². This principle applies with particular force to non-official data sources, where measurement methods may not conform to established statistical standards.

¶3 This section provides guidance on four key aspects of working with citizen science and community-based monitoring data: the types of programs that generate relevant data, the quality considerations that must be addressed, approaches for integration with official statistics, and compilation procedures for processing citizen science observations into account-ready datasets. For general principles of data quality applicable across all ocean accounting work, see **TG-0.7 Quality Assurance Principles**.

3.1 Types of Citizen Science Programs

¶1 Marine citizen science covers a range of programmes in which volunteers participate in scientific data collection. These programmes vary in their structure, the types of data collected, and their potential relevance to ocean accounting. For the purposes of this guidance, citizen science programmes can be organised into several categories based on their primary focus and methodology.

¶2 Several established programmes in the Pacific region illustrate the range and maturity of marine citizen science, including the reef monitoring programmes described in Section 3.2. These programmes demonstrate that well-designed citizen science can produce data suitable for monitoring ecosystem condition variables relevant to ocean accounts.^{3, 4, 5, 6, 7}

Biological monitoring programs

¶1 Many marine citizen science programmes document the presence, abundance, or condition of marine species. Table 3.1.1 below summarises the main types.

Program type	Description
Reef monitoring programs	Volunteers conduct standardized surveys of coral reef health, recording coral cover, bleaching events, and associated fauna. Programs such as Reef Check have developed standardized protocols that enable consistent data collection across sites and time periods ³ .
Seabird and marine mammal counts	Coastal bird counts and marine mammal sightings programs engage volunteers in systematic observations that contribute to population monitoring. These programs often have long histories that provide valuable time series data ⁸ .

Program type	Description
Fish identification and abundance surveys	Recreational divers and snorkelers contribute observations of fish species and abundance, particularly in areas of high recreational use such as marine parks ⁵ .
Intertidal zone surveys	Volunteers survey rocky shores, mudflats, and other intertidal habitats, documenting species assemblages and environmental conditions ⁹ .

¶2 These biological monitoring programmes may contribute to ecosystem condition accounts under the SEEA EA framework, particularly for variables relating to species diversity and population status. The *Technical Guidance on Biophysical Modelling for SEEA Ecosystem Accounting* notes that “in situ monitoring and accuracy assessments of ecosystem services maps” are needed, and that “standardized approaches for in situ monitoring of ecosystem services is even less well established than modelling approaches”^{10, 11}.

Environmental quality monitoring

¶1 Citizen science programmes also collect data on environmental conditions that may be relevant to ocean accounts. Table 3.1.2 below summarises the main environmental quality monitoring types.

Program type	Description
Water quality monitoring	Community groups collect samples and measurements of parameters such as temperature, salinity, turbidity, and nutrient levels. The FDES notes that “field-monitoring stations, especially those monitoring concentrations of pollutants in the environmental media, are usually located in ‘hot spot’ areas with high levels of pollution” ¹² , suggesting that citizen science monitoring may help fill spatial gaps in official networks.
Marine debris surveys	Beach cleanup programs systematically document the quantity and types of marine debris, providing data on pollution pressures on coastal ecosystems ¹³ . Such data may be relevant to indicators discussed in TG-2.1 Aggregate Biophysical Indicators of Environmental State and directly support marine litter accounts in TG-6.12 Marine Litter and Plastics Accounting .
Phytoplankton and harmful algal bloom monitoring	Volunteers collect water samples to monitor for harmful algal blooms that can affect human health and fisheries ¹⁴ .

Observational reporting

¶1 Less structured citizen science approaches rely on opportunistic observations:

- ¶2 **Species sighting platforms** – Online platforms and mobile applications enable members of the public to report sightings of marine species, contributing to distribution records and phenological data¹⁵.
- ¶3 **Environmental incident reporting** – Community members report pollution events, strandings, and other environmental incidents that may not be captured by official monitoring¹⁶.

Community-based monitoring

¶1 Ongoing engagement by local communities in environmental observation, often reflecting long-term community interest in local resources and potentially incorporating traditional knowledge and practices. Community-based monitoring differs from the above categories in data ownership structures and consent obligations. Section 3.4 sets out the operational distinctions.

Mapping to SEEA EA account types

¶1 The table below cross-references each citizen science program category against the principal SEEA EA account types and the maximum tier at which contribution is currently considered feasible. Entries marked with a dagger (†) are contested or jurisdiction-dependent.

¶2 *Table 3.1.1: Citizen Science Program Categories Mapped to SEEA EA Account Types*

CS Program Category	Ecosystem Extent	Ecosystem Condition	Ecosystem Services Flows	Material Flows
Biological monitoring	Tier 2 (habitat patch)	Tier 3	Tier 2	n/a
Environmental quality	Tier 1 †	Tier 2	Tier 1 †	Tier 2 (pollution)
Observational reporting	Tier 1 †	Tier 2	Tier 1	n/a
Community-based monitoring	Tier 2	Tier 3	Tier 2	Tier 2

¶3 **Notes:** “n/a” indicates the combination is not currently feasible. Extent contributions from observational/environmental quality programs are contested (†) because species sighting platforms do not constitute systematic habitat surveys. Community-based monitoring can reach Tier 3 for condition only where sustained protocol-adherent programs exist with overlapping official validation data.

3.2 Data Quality Considerations

¶1 The UN NQAF quality dimensions and overarching framework are in **TG-0.7 Quality Assurance Principles** and **TG-4.5 Research Data Section 3.3.1**. Citizen-science-specific quality risks are summarised in Table 3.2.1¹⁷.

¶2 *Table 3.2.1: Citizen science quality risks*

Source	Description
Observer variability	Volunteers vary in experience and identification skill; training and certification reduce but do not eliminate this ¹⁸ .
Sampling bias	Observations cluster in accessible locations and favourable conditions, producing non-random spatial and temporal coverage ¹⁹ .
Measurement protocols	Variations in how volunteers interpret and apply standardised instructions introduce measurement error ²⁰ .

¶3 Generic validation methods for non-official sources (expert verification, comparison with official monitoring, internal consistency screening, photographic evidence) are in **TG-4.5 Section 3.3.1**²¹. Step-by-step citizen-science application is in Section 3.5 (Steps 7–8).

¶4 Uncertainty characterisation must document known biases, precision estimates (from replicate observations or reference-data comparison), and completeness (spatial/temporal coverage and gaps)^{22, 23}. The Section 3.5 worked example illustrates uncertainty propagation through a Tier 2 compilation.

3.3 Integration with Official Statistics

¶1 Integrating citizen science data with official statistics requires clear methodological protocols that maintain the integrity of official data whilst drawing on the contribution of citizen science.

Tiered integration approaches

¶1 Drawing on the tiered approach to data quality described in the *Technical Guidance on Biophysical Modelling* (paras. 53–55), which distinguishes tiers by modelling complexity and

data availability, this Circular proposes an analogous tiered framework for citizen science data integration. This tiering follows the graduated capacity framework described in **TG-0.7 Quality Assurance Principles**.

- ¶2 **Tier 1** approaches use citizen science data for awareness-raising, education, and analysis of broad patterns, without integration into official accounts²⁴.
- ¶3 **Tier 2** approaches use citizen science data to supplement official data where coverage is limited, with appropriate uncertainty characterisation and metadata²⁵.
- ¶4 **Tier 3** approaches involve formal calibration of citizen science data against official monitoring, with the data meeting the country's own official statistics quality standards for direct integration²⁶.

¶5 The appropriate tier depends on the application, the quality of the citizen science data, and the availability of official data. Most current applications of citizen science data in environmental accounting operate at Tier 1 or Tier 2 levels.

¶6 Table 3.3.1 summarises the characteristics, quality requirements, and typical applications of each tier.

¶7 *Table 3.3.1: Citizen Science Data Quality Tiers for Ocean Accounts*

Tier	Role in Accounts	Quality Requirements
Tier 1: Awareness	Gap identification, hypothesis generation	Minimal validation
Tier 2: Supplementary	Fill data gaps with caveats	Moderate validation, uncertainty documented
Tier 3: Formal	Direct account input	Meets national official statistics quality standards; calibrated against overlapping official data; no unaccounted systematic bias; uncertainty documented – see checklist below

Tier assignment decision checklist

¶1 The following checklist guides tier assignment for a citizen science dataset. Mixed-tier assignment within a single dataset is explicitly permitted – for example, calibrated data from overlapping sites may qualify as Tier 3 whilst data from non-overlapping sites remain Tier 2. In account tables, each subset must be labelled with its assigned tier and associated uncertainty.

¶2 **Tier 1 – Minimum criteria:**

- ¶3 ☐ Data have undergone initial screening per Section 3.5 Step 3
- ¶4 ☐ Spatial and temporal coverage are documented in metadata
- ¶5 ☐ Data are not presented as direct account estimates

¶6 **Tier 2 – Additional criteria (all Tier 1 criteria plus):**

- ¶7 ☐ Bias sources (spatial, temporal, observer) have been assessed and documented (Section 3.5 Steps 4–5)
- ¶8 ☐ Uncertainty has been quantified and attached to any summary statistics
- ¶9 ☐ Data have undergone at least one form of validation (expert review, internal consistency checks, or comparison with official data where available)
- ¶10 ☐ Known limitations are disclosed in account metadata

¶11 **Tier 3 – Additional criteria (all Tier 2 criteria plus):**

- ¶12 ☐ Calibration has been conducted against overlapping official monitoring data (Section 3.5 Step 7)
- ¶13 ☐ The citizen science data meet the country's official statistics quality standards as applied to other data sources used in that account compilation – the applicable quality standard is

country-specific and should be documented

- ¶14 ☐ Residual uncertainty after calibration has been estimated and documented
- ¶15 ☐ No systematic bias remains that has not been accounted for and reported

¶16 Compilers exercise professional judgement in determining whether calibration evidence is sufficient for the intended account use. Some citizen science programs are contextual or trend-oriented and will appropriately remain at Tier 1 or Tier 2 regardless of calibration effort. If sufficient calibration evidence cannot be assembled, the data should be assigned Tier 2, not Tier 3.

¶17 **Program continuity and trend-capable tier assignment:** Where citizen science data are to be used for trend detection or multi-year condition assessment, tier assignment must also consider program continuity. As a guide, trend-capable assignment at Tier 2 or Tier 3 requires at least two independent accounting periods of data collected under consistent protocols. Calibration relationships derived from a single season or year should be applied to other periods only where there is documented evidence of protocol, volunteer pool, and survey effort stability across years. Where program continuity is uncertain – a common situation for SIDS programs with discontinuous funding – compilers should restrict use of the data to within-period reporting and flag the program continuity limitation in account metadata.

Metadata and provenance

¶1 When incorporating citizen science data, metadata should document:

- ¶2 The citizen science program and its protocols
- ¶3 Training and quality assurance procedures applied
- ¶4 Any validation or calibration conducted
- ¶5 Known limitations and biases
- ¶6 The relationship between citizen science data and any official data used in the same accounts

¶7 FAIR principles and domain-specific metadata standards (ISO 19115, Darwin Core, SDMX) applicable to all ocean accounting data sources, including citizen science, are described in **TG-4.5**

Integrating Research Data into Official Statistics Section 3.4 and **TG-4.6 Data Harmonisation and Interoperability Section 3.1**. Citizen science datasets should be clearly distinguished from official data sources in account tables, using separate columns, footnotes, and uncertainty ranges, so that users can assess fitness for purpose. The quality-tier labelling scheme described in Section 3.3 of this Circular implements that requirement.

3.4 Community-Based Monitoring

¶1 Community-based monitoring is a distinct form of participatory data collection that involves ongoing engagement by local communities in environmental observation. In contrast to project-based citizen science, community-based monitoring often reflects long-term community interest in local resources and may incorporate traditional knowledge and practices.

Coastal community monitoring

¶1 In many coastal contexts, fishing communities, coastal residents, and marine resource user groups conduct informal or semi-formal monitoring of local conditions. This monitoring may encompass:

- ¶2 Observations of fish abundance and species composition
- ¶3 Documentation of changes in coastal habitats
- ¶4 Recording of environmental conditions relevant to fishing and other livelihoods
- ¶5 Monitoring of resource access and use

¶6 The Taskforce on Nature-related Financial Disclosures (TNFD) recommendations recognise the importance of engagement with “Indigenous Peoples, Local Communities and affected stakehold-

ers” in assessment of nature-related issues²⁷. Whilst the TNFD framework addresses corporate disclosure rather than official statistics, the underlying principle – that local communities hold detailed knowledge of their environments – applies equally to ocean accounting.

¶7 Several Pacific Island community-based monitoring programs illustrate the potential for contributing to ocean accounts. In Fiji, the Locally-Managed Marine Area (LMMA) Network coordinates community-based monitoring of coral reef and coastal fisheries across more than 400 communities, using standardized protocols adapted to local capacity and generating long-term time series data on reef fish abundance and coral cover²⁸. In American Samoa, village-based fisheries monitoring programs have documented changes in coastal fish stocks using methods combining traditional fisher knowledge with structured survey protocols²⁹. In Palau, community monitoring of giant clam populations has provided data used in both fisheries management and ecosystem condition assessment³⁰. These programmes demonstrate that sustained community engagement can yield data of sufficient quality and consistency to support accounting applications, particularly at Tier 2 level.

Compilation steps requiring modification for community-based monitoring

¶1 ⓘ **Community-Based Monitoring: Compilation Modifications**

¶2 The compilation procedure in Section 3.5 applies to community-based monitoring datasets, but the following steps require modification:

- ¶3 **Step 2 (Data acquisition):** Data held by communities may not be lodged with a program coordinator. Compilers must negotiate access directly with community governance bodies before requesting data. Standard data-sharing agreements used for government-to-government data exchange are generally not appropriate. A co-designed data access agreement that recognises community data ownership is required.
- ¶4 **Before any data use:** FPIC documentation is required before community-based monitoring data are incorporated into accounts – not merely before publication. See the FPIC checklist below.
- ¶5 **Step 10 (Metadata):** Data sovereignty obligations may restrict what metadata can be published. Communities retain the right to determine the level of spatial and programmatic detail that appears in public account documentation. Metadata fields that would reveal sensitive resource locations or culturally restricted information must be withheld or generalised on community instruction.
- ¶6 **Tier classification and publication:** Communities have the right to restrict the tier at which their data are classified or to prevent publication of specific account series. Where a community exercises this right, the compiler should document the restriction in internal records and present the affected series as “Data held – publication restricted” in public account tables.

¶7 See **TG-3.6 Traditional Knowledge** for the full protocol governing traditional knowledge integration.

FPIC documentation checklist

¶1 The following checklist specifies the minimum documentation a national statistics office must retain to demonstrate that FPIC was obtained before community-based monitoring data were incorporated into official accounts:

- ¶2 ☐ **Consent record format:** Written consent on record in a format agreed with the community (written, witnessed oral record, or community council resolution as appropriate to local governance norms). Retention period: not less than the publication life of the account series plus 10 years.
- ¶3 ☐ **Named signatories:** Consent document identifies the community governance body and individual(s) authorised to provide consent on the community’s behalf, with reference to their governance role.
- ¶4 ☐ **Scope of consent:** Consent explicitly covers: (a) which data series are covered; (b) permitted uses (internal quality control, published accounts, supplementary material); (c) tier classification; (d) geographic scope of publication; and (e) duration of consent.
- ¶5 ☐ **Withdrawal process:** Consent document or covering agreement specifies the process for withdrawal of consent, including: notice period, method of notification, and process for retrospective amendment of published accounts where withdrawal occurs after publication.

- ¶6 ☐ **Stronger national law:** Where national law (including Indigenous data sovereignty legislation) provides stronger protections than the Nagoya Protocol or UNDRIP minimum standards, the national law standard applies and must be documented.

¶7 Cross-reference: **TG-3.6 Traditional Knowledge** for the full traditional knowledge protocol.

Retrospective data governance for historical datasets

¶1 Many account compilation exercises draw on historical citizen science or community-based monitoring records collected before modern FPIC and data sovereignty standards existed. Compilers applying the above FPIC standards to historical datasets should apply the following procedure according to the applicable scenario:

¶2 **(a) Waiver of consent:** Where data are fully anonymised or aggregated to a level that prevents identification of individual community members or of specific community lands, and where collection was lawful at the time of collection, an institutional ethics review may authorise continued use.

¶3 **(b) Community-level authorisation:** Where data relate to Indigenous community lands, resources, or cultural heritage – regardless of whether individual consent was obtained at the time of collection – engagement with the current community governance body is required before data are incorporated into accounts. Community-level authorisation replaces the requirement for individual historical consent.

¶4 **(c) Use-limitation:** Where neither waiver nor community-level authorisation is achievable (for example, where governance structures have dissolved or community representatives cannot be identified), the data may be retained for internal quality control but must not appear in published accounts.³¹

¶5 In all three scenarios, document the consent status and data classification in the metadata record before use. Use-limitation series must be flagged as unavailable for public release.

CARE principles and data system design

¶1 The CARE principles (Collective Benefit, Authority to Control, Responsibility, Ethics) provide a framework for Indigenous data governance that complements FAIR principles.³² Where ocean accounts draw on community-based monitoring, CARE constraints must be embedded in data system design before data collection begins:

- ¶2 **Collective Benefit:** Account outputs must be interpretable and accessible to source communities, not solely to NSO end-users. Data systems should produce community-facing reports in formats agreed with communities, not only statistical tables for national publication.
- ¶3 **Authority to Control:** Data systems must implement tiered access controls that can restrict or revoke access on community instruction, with provenance metadata linking each data series to the community of origin. A community must be able to instruct the NSO to remove or restrict a data series without requiring the community to justify the instruction.
- ¶4 **Responsibility:** Co-management arrangements between NSOs and communities are required. Data extraction without reciprocal benefit to the community, including capacity building and access to account outputs, is inconsistent with CARE alignment.
- ¶5 **Ethics:** Community decisions to restrict publication of culturally sensitive indicators take precedence over standard statistical dissemination obligations. Where a conflict arises between CARE obligations and statutory publication requirements, legal advice should be sought before publication proceeds.

¶6 CARE complements but does not replace FAIR principles. Data systems should satisfy both frameworks simultaneously where possible. Cross-reference: **TG-3.6 Traditional Knowledge**.

Data classification framework

¶1 The following table specifies default access classification levels for ocean account data series involving citizen science or community-based monitoring data. Compilers must record the classification basis as a required metadata field for each data series.

¶2 *Table 3.4.1: Default Data Access Classification by Account Type*

Account Type	Default Classification	Basis	Notes
Ecosystem extent – remote sensing or aggregated survey	Open	Statistical dissemination obligation	No enterprise-level data; no sensitive species locations
Ecosystem condition – aggregated citizen science	Open with spatial generalisation	Statistical dissemination obligation	Apply spatial sensitivity protocol (Section 3.5 Step 2) for sensitive species
Ecosystem services flow – commercial (fisheries, aquaculture)	Restricted at enterprise level; open at aggregate account level	Statutory confidentiality (enterprise records)	Aggregate totals may be published; cell suppression required where fewer than 3 enterprises
Material flow – waste, pollution	Open	Statistical dissemination obligation	Check for commercially sensitive supplier data
Community-based monitoring data under FPIC agreement	Consent-conditional	Indigenous data sovereignty / FPIC scope	Access level determined by consent scope; document consent record reference

¶3 Classification basis must be documented in account metadata. Where classification is consent-conditional, the metadata record must reference the FPIC documentation (consent record identifier and date).

Integration with traditional knowledge

¶1 Community-based monitoring often draws upon, or is informed by, traditional ecological knowledge. The relationship between community-based monitoring and traditional knowledge systems requires respectful engagement with knowledge holders. Detailed guidance on working with traditional knowledge is provided in **TG-3.6 Traditional Knowledge**.

¶2 Engagement with traditional knowledge requires FPIC, respect for intellectual property and cultural protocols, proper attribution in accounts metadata, and reciprocal benefit to communities – see **TG-3.6 Traditional Knowledge** for the full protocol.^{33, 34, 35, 36}

¶3 The TNFD recommendations include guidance on engagement of Indigenous Peoples, Local Communities and affected stakeholders, emphasising that organisations should “describe the Indigenous Peoples, Local Communities and affected stakeholders engaged in the assessment and management of nature-related dependencies, impacts, risks and opportunities, how they were identified, and a confirmation that this description has been agreed with those engaged”³⁷.

3.5 Compilation Procedures

¶1 This section provides practical guidance on the procedures for compiling citizen science data into ocean accounts, addressing data acquisition, processing, quality control, and integration steps.

Data acquisition and screening

¶1 The first stage of compilation involves acquiring citizen science data and conducting initial screening for quality issues:

¶2 **Step 1: Identify relevant programs** – Survey available citizen science and community-based monitoring programs operating in the accounting area. For marine contexts, priority programs typically include:

- ¶3 Beach litter surveys (e.g., Ocean Conservancy International Coastal Cleanup, OSPAR Beach Litter Monitoring)
- ¶4 Reef monitoring programs (e.g., Reef Check, CoralWatch)
- ¶5 Marine species sighting platforms (e.g., iNaturalist, eBird for seabirds)
- ¶6 Water quality monitoring networks (community-based programs)

¶7 **Step 2: Request data and documentation** – Contact program coordinators to request:

- ¶8 Raw observational data (species counts, condition scores, litter counts, water quality measurements)
- ¶9 Program protocols and standard operating procedures
- ¶10 Training materials and observer qualifications
- ¶11 Quality control procedures applied by the program
- ¶12 Metadata on survey locations, dates, and conditions

¶13 For community-based monitoring datasets, data access negotiation must follow the community-based monitoring compilation modifications described in Section 3.4 before data are requested.

¶14 **Spatial data sensitivity protocol:** When acquiring species occurrence data, apply the GBIF Best Practices for Generalising Sensitive Species Occurrence Data³⁸ sensitivity classification before publication. Four sensitivity categories apply, with corresponding coordinate generalisation standards:

Sensitivity Category	Description	Coordinate Generalisation
Category 1 – Extreme	Species at imminent extinction risk; commercially targeted at national scale	~1° decimal degrees
Category 2 – High	Threatened species; significant cultural/commercial sensitivity	0.1° decimal degrees
Category 3 – Medium	Near-threatened; moderate exploitation risk	0.01° decimal degrees
Category 4 – Low	No identified sensitivity	0.001° decimal degrees (or full precision)

¶15 Coordinate generalisation – retaining spatially valid but imprecise data – is preferred over randomisation, which introduces false coordinates that cannot be corrected downstream. Metadata for each generalised series must record: stored coordinate precision, published coordinate precision, coordinate uncertainty radius (metres), sensitivity category, sensitivity reason, and review date.

¶16 **Conflict of interest assessment:** Before accepting a citizen science dataset, record whether any data-collecting organisation has a material financial interest in account outcomes – for example, regulatory compliance status, grant eligibility, or market certification that depends on account values. Data series from providers with a material financial interest must be flagged for independent cross-validation before assignment above Tier 1. The independence assessment must be documented in account metadata. Where independent cross-validation is not feasible, conflicted data series should be restricted to supplementary or sensitivity analysis use.³⁹

¶17 **Step 3: Conduct initial screening** – Apply automated checks to flag obvious errors:

- ¶18 Values outside physically plausible ranges (e.g., negative counts, impossible measurements)
- ¶19 Locations outside the survey area or on land (for marine observations)
- ¶20 Dates outside the survey period or in the future
- ¶21 Duplicate records

¶22 Remove flagged records or query program coordinators for clarification. Document the number and proportion of records removed at this stage.

Bias assessment and correction

¶11 **Step 4: Assess spatial bias** – Map the distribution of citizen science observations and compare with the desired coverage:

- ¶12 Calculate the density of observations per unit area
- ¶13 Identify areas with high and low coverage
- ¶14 Compare coverage with population density, road networks, and accessibility indicators to identify biases

¶15 For reef monitoring as an example, observations may be heavily concentrated near dive shops and tourist areas. Document this spatial bias in metadata and, where necessary, stratify the dataset to avoid over-weighting accessible sites.

¶16 **Step 5: Assess temporal bias** – Analyse the temporal distribution of observations:

- ¶17 Plot observations by month, season, and year
- ¶18 Identify periods with high and low coverage
- ¶19 Compare with weather patterns and program schedules

¶10 Beach litter surveys, for instance, may be concentrated during organised cleanup events, missing inter-event accumulation. Document temporal bias and consider time-stratified sampling for trend estimation.

¶11 **Fallback temporal bias procedure for programs without sentinel sites:** Where a program does not have sentinel or reference sites available for cross-validation (for example, retrospective analysis of historical datasets or volunteer programs with no resource for sentinel deployment), apply the following fallback procedure:

1. ¶12 Analyse time-series autocorrelation in the citizen science dataset to identify event-driven observation spikes that indicate temporal clustering.
2. ¶13 Compare the temporal distribution of observations against publicly available environmental proxy data (for example, satellite-derived sea surface temperature, wind speed records, or rainfall indices) to identify weather-driven observation gaps.
3. ¶14 Document the findings of the autocorrelation and proxy comparison analyses in metadata.

¶15 Where temporal bias cannot be adequately characterised or corrected using this fallback procedure, the data should be restricted to Tier 1 or Tier 2, with a metadata note stating that temporal coverage is insufficient for Tier 3 calibration.

¶16 **Step 6: Apply bias corrections where justified** – For some applications, statistical corrections for known biases may be appropriate:

- ¶17 Distance from access point corrections for spatial bias
- ¶18 Weather condition corrections for temporal bias
- ¶19 Occupancy modelling for detection probability (for species sightings data only where replicated detection/non-detection data are available at sites visited on multiple occasions – see caution below)

¶20 **Occupancy modelling decision criterion:** Occupancy modelling is warranted only where the dataset includes replicated detection/non-detection records at sites visited on at least two independent occasions. Where this condition is not met, effort standardisation (dividing observation counts by survey effort, e.g., observer-hours or transect length) is the preferred approach. Occupancy modelling requires specialist statistical support and should not be attempted without relevant expertise. The `unmarked` R package⁴⁰ provides accessible implementation guidance for qualified practitioners.

¶21 Apply corrections conservatively and document methods. Where correction is not feasible, restrict use of the data to applications where the bias does not compromise fitness for purpose (e.g.,

use spatially biased data only for trend monitoring at sampled sites, not for total stock estimation).

Validation and calibration

¶1 **Step 7: Cross-validate with official data** – Where citizen science and official monitoring overlap in space and time:

- ¶2 Extract paired observations from both sources
- ¶3 Calculate correlation coefficients and regression relationships
- ¶4 Assess systematic biases (e.g., consistent under- or over-estimation)
- ¶5 Estimate measurement error variances

¶6 For Tier 3 integration, calibration functions can be derived from these comparisons. For example, if citizen science beach litter counts are consistently 80% of professional survey counts (due to incomplete area coverage), a calibration factor of 1.25 can be applied with documented uncertainty.

¶7 Citizen science data submitted for Tier 3 integration should be assessed with the same expectations of scientific rigour – including sample size adequacy and regression model selection – as any other scientific data source used in compilation. The same professional judgement applied to other data sources governs the adequacy of calibration evidence. Prescriptive minimum thresholds are not specified because the appropriate standard varies across citizen science program types and national statistical quality frameworks. Some citizen science programs are contextual in nature or suitable only for trend analysis, and will appropriately remain at Tier 1 or Tier 2 even where calibration data exist. Compilers should document the basis for this determination. Where calibration evidence is insufficient for the intended account use, the data should default to Tier 2.

¶8 **Step 8: Expert review of flagged observations** – For observations that fail consistency checks but may be valid:

- ¶9 Compile sets of unusual observations (e.g., rare species, extreme values)
- ¶10 Request expert review from taxonomists or subject matter specialists
- ¶11 Verify observations with photographic evidence where available
- ¶12 Accept, reject, or flag as uncertain based on expert judgment

¶13 Document the number of observations reviewed and the proportion accepted, rejected, or flagged.

Dataset preparation and integration

¶1 **Step 9: Aggregate to accounting units** – Transform point observations to the spatial and temporal units used in accounts:

- ¶2 For ecosystem condition accounts: aggregate observations to Basic Spatial Units (BSUs) or Ecosystem Accounting Areas (EAAs)
- ¶3 For time series accounts: aggregate to annual or sub-annual periods
- ¶4 Calculate summary statistics (mean, median, standard deviation) for each unit
- ¶5 Estimate uncertainty (standard errors, confidence intervals)

¶6 For example, citizen science reef condition observations would be aggregated to reef ecosystem polygons, with mean coral cover and associated confidence intervals calculated for each polygon.

¶7 **Note on spatial coverage and interpolation:** Citizen science observations that fall outside the boundaries of an accounting area cannot be used to characterise that accounting area. Where spatial interpolation is applied to extend observations within an accounting area, it should be treated with the same rigour applied to any other scientific data source: if the resulting uncertainty is too high, the unit should be flagged as “insufficient data” rather than assigned an estimate. Whether interpolation is appropriate also depends on data type and the spatial resolution required to

meaningfully characterise the accounting unit – interpolation from distant observations is inappropriate where high spatial resolution is required, regardless of whether uncertainty bounds can be calculated.

¶8 **Note on uncertainty in combined estimates:** When account totals combine official monitoring estimates and citizen science estimates, three sources of additional uncertainty warrant specific attention: (a) double-counting risk where datasets overlap spatially – compilers must verify that the same observations are not contributing to both official and citizen science subtotals; (b) calibration uncertainty, which is a systematic component correlated across all citizen science observations from a given program and must not be treated as random error; and (c) temporal propagation uncertainty, which accumulates when citizen science estimates are used to extend time series beyond the calibration period. For formal propagation methods, see the SEEA EA uncertainty annex⁴¹.

¶9 **Step 10: Compile metadata and provenance** – For each citizen science dataset integrated into accounts, compile metadata including:

- ¶10 Programme name and coordinating organisation
- ¶11 Survey methods and protocols
- ¶12 Observer training and qualifications
- ¶13 Quality control procedures applied
- ¶14 Known biases and limitations
- ¶15 Validation and calibration procedures
- ¶16 Tier classification (Tier 1, 2, or 3)
- ¶17 Period of data collection
- ¶18 Number of observations and spatial coverage
- ¶19 Data classification basis (see Table 3.4.1)
- ¶20 Conflict of interest assessment outcome
- ¶21 For community-based monitoring: FPIC documentation reference and consent scope

¶22 This metadata should accompany the accounts as supplementary documentation.

¶23 **Step 11: Deliver citizen science estimates separately identified** – Never merge a citizen science estimate into an official series without a marker. Deliver:

- ¶24 The citizen science estimate as its own series, not blended into the official one
- ¶25 The data source and quality tier against each value
- ¶26 An uncertainty range for every citizen science value

¶27 For example, coral cover is delivered as two labelled series – “Coral cover (official monitoring)” and “Coral cover (citizen science, Tier 2)” – each with its confidence interval, so that the compiling circular can decide whether to present them as separate account columns, combine them, or use one to validate the other.

Worked example: Beach litter data compilation

¶1 A concrete worked example illustrates the compilation procedure. A statistical office compiling marine litter accounts (see **TG-6.12 Marine Litter and Plastics Accounting**) receives beach litter survey data from the Ocean Conservancy International Coastal Cleanup program for 85 beach sites surveyed over a three-year period. The compilation steps are:

¶2 **Step 1-2:** Acquire data including litter counts by material category, beach lengths surveyed, and survey dates. Obtain program protocols specifying survey methods. Conflict of interest assessment confirms the International Coastal Cleanup program has no material financial interest in account outcomes (non-governmental, no regulatory or grant linkage to account values).

¶3 **Step 3:** Screen data, identifying and removing 8 records with impossible dates and 3 records with beach lengths exceeding known beach dimensions (0.97% of records removed).

¶4 **Step 4:** Map survey sites. Survey coverage concentrates in urban coastal areas (72% of surveys within 20km of cities > 50,000 population). Document spatial bias, and restrict use of data to “beach litter density at surveyed sites” rather than extrapolating to all coastlines.

¶5 **Step 5:** Plot temporal distribution. Observations concentrate on cleanup event dates (September International Coastal Cleanup Day = 58% of observations). Supplement with quarterly surveys at 12 sentinel sites to capture inter-event periods.

¶6 **Step 6:** No bias correction applied. Instead, stratify reporting by urban/remote and event/non-event categories.

¶7 **Step 7:** Compare 12 sentinel sites with professional monitoring, finding citizen science counts average 85% of professional counts (95% CI: 78-92%). Derive calibration factor of 1.18 ($=1/0.85$) for Tier 3 use, with uncertainty range of 1.09-1.28. Calibration evidence assessed as adequate for the intended account application (litter density estimates at monitored sites). The professional judgement basis for this determination is documented in the methodology note.

¶8 **Step 8:** Expert review not required for litter counts (straightforward enumeration), but material categorisation reviewed by 2 marine debris specialists for 10% of surveys, with 94% agreement.

¶9 **Step 9:** Aggregate to coastal administrative units (districts), calculating mean litter density (items per meter of beach) and total estimated stock (items) with confidence intervals reflecting sampling error and calibration uncertainty. Calibration uncertainty is treated as a systematic component (correlated across all citizen science observations) and is combined separately from random sampling error. No spatial interpolation is applied to districts without citizen science coverage. These districts are flagged as “insufficient data.”

¶10 **Step 10:** Compile metadata documenting International Coastal Cleanup protocols, volunteer training (brief on-site instruction), known biases (urban concentration, event concentration), validation results (85% of professional counts), conflict of interest assessment (none), and Tier 2/3 classification (Tier 3 for calibrated data at overlapping sites, Tier 2 for data at non-overlapping sites).

¶11 **Step 11:** Deliver to **TG-6.12 Marine Litter and Plastics Accounting** three separately identified estimates:

- ¶12 Beach litter stock (official monitoring): 450,000 items (95% CI: 410,000-490,000) [12 sites]
- ¶13 Beach litter stock (citizen science, Tier 2, calibrated): 1,850,000 items (95% CI: 1,630,000-2,070,000) [73 non-overlapping sites]
- ¶14 Combined total (official + citizen science non-overlapping sites): 2,300,000 items (95% CI: 2,077,000-2,523,000, computed by summing variances as if the estimates were independent, which understates the interval because the calibration factor is derived from the official sentinel-site counts: $SE_{combined} = \sqrt{20,400^2 + 112,200^2} \approx 114,000$)

¶15 This worked example demonstrates the practical steps and decision points in citizen science data compilation. Key principles illustrated include: transparent documentation of data processing decisions, restriction of data use to applications appropriate for the quality tier, derivation of calibration factors from overlap with official data, and clear communication of uncertainty.

3.6 Decision Use Cases for Citizen Science Data

¶1 The following use cases illustrate the tier assignments and quality requirements set out in Section 3.3. This section describes decision contexts where citizen science data can support ocean accounting and related policy analysis, illustrating how the compilation procedures described in Section 3.5 apply in practice.

Gap-filling for data-sparse coastal areas

¶1 Many coastal nations, particularly Small Island Developing States (SIDS), have limited resources for establishing official monitoring networks with wide spatial coverage. Citizen science can provide observations in areas that would otherwise have no data:

¶2 **Use case:** A Pacific SIDS conducts official reef monitoring at 8 sites, providing high-quality data but covering only 5% of reef area. Reef Check volunteer surveys add 45 sites, increasing coverage to 35% of reef area. Whilst the volunteer data are less precise (Tier 2), they enable spatial stratification of condition estimates and identification of priority areas for management intervention. The combined dataset (official + citizen science) supports ecosystem condition accounts that would not be feasible with official data alone.

¶3 **Decision support:** Marine spatial planning authorities use the expanded dataset to identify degraded reef areas requiring protection and relatively intact areas suitable for tourism zoning. Without citizen science data, planning would proceed on the basis of limited site coverage or coarse remote sensing proxies.

Supplementing temporal resolution for trend detection

¶1 Official monitoring programs often operate on multi-year cycles due to resource constraints. Citizen science can provide higher-frequency observations:

¶2 **Use case:** A national coastal water quality program samples 30 estuaries biennially. A community-based monitoring network samples 15 of these estuaries monthly. The citizen science data capture seasonal variation and enable detection of short-term pollution events that would be missed by biennial sampling. When calibrated against the official biennial data (Tier 3 approach), the citizen science time series provide improved trend detection for nitrogen concentrations and turbidity.

¶3 **Decision support:** Watershed managers use the high-frequency citizen science data to identify seasonal pollution patterns linked to agricultural runoff timing. These patterns support targeted interventions. The biennial official data alone would not reveal these temporal patterns.

Beach litter monitoring for marine pollution accounts

¶1 Beach litter surveys are one of the most established applications of citizen science in marine environmental monitoring, with direct relevance to SDG 14.1 (marine pollution) and marine litter accounts (see **TG-6.12 Marine Litter and Plastics Accounting**):

¶2 **Use case:** A coastal nation compiles marine litter accounts drawing on beach litter survey data from the International Coastal Cleanup and regional monitoring programs. Annual cleanup events engage 5,000–8,000 volunteers surveying 200–300 beach sites. Data are standardised using Ocean Conservancy protocols, enabling material categorisation and source attribution (land-based vs. sea-based litter).

¶3 **Decision support:** The marine litter accounts combine citizen science survey data with waste management statistics. They reveal that single-use plastics from coastal tourism comprise 42% of beach litter by item count. This attribution supports targeted policy interventions including bans on specific single-use items and tourism operator education programmes. The spatial distribution of citizen science observations identifies pollution hotspots requiring enhanced cleanup and enforcement.

¶4 This decision context is particularly relevant for SIDS where beach tourism is economically important and beach aesthetics affect visitor satisfaction. Citizen science provides cost-effective, large-scale monitoring that would be prohibitively expensive to conduct through official programmes alone.

Reef condition reporting for ecosystem accounts

¶1 Coral reef condition is a priority indicator for many Pacific and Caribbean nations. Citizen science reef monitoring programs provide data for ecosystem condition accounts:

¶2 **Use case:** Reef Check volunteer diver surveys complement official scientific monitoring, providing observations from 60 reef sites compared to 15 official sites. Volunteers record coral cover, bleaching incidence, and fish abundance using standardised underwater survey forms. Data undergo expert validation (photographic verification of coral identifications) and calibration against professional surveys at 10 overlapping sites.

¶3 **Decision support:** The expanded spatial coverage enables ecosystem condition accounts stratified by reef type (fringing, barrier, atoll) and management status (protected vs. unprotected). Trend analysis reveals that condition is declining faster in unprotected areas, supporting expansion of marine protected area networks. The citizen science data provide the spatial coverage necessary for meaningful stratification that would not be possible with official monitoring alone.

¶4 ⓘ **Compiling Ordinal Citizen Science Data**

¶5 Reef condition programs such as Reef Check and CoralWatch produce ordinal or semi-quantitative scores (e.g., bleaching categories 1–5, or coral cover estimated visually in 5% bands) rather than continuous measurements. Arithmetic means of ordinal scores are statistically inappropriate. Compilers working with these data types should apply the following conventions:

- ¶6 **Summary statistics:** Use median and interquartile range (IQR) rather than mean and standard deviation. Present frequency distributions (proportion of observations in each category) alongside median and IQR.
- ¶7 **Trend expression:** Express trends as the change in proportion of observations falling in each category between periods (e.g., “the proportion of surveys recording bleaching at category 3 or above increased from 18% to 34%”). Rank-based trend tests (Kendall’s tau) are appropriate for ordinal time series.
- ¶8 **Uncertainty representation:** Report the proportion-in-category with a binomial confidence interval for each category. Do not combine ordinal category estimates into a single composite index without documented justification and reference to the SEEA EA guidance on discrete condition variable aggregation⁴².
- ¶9 **Delivered form:** Deliver ordinal condition data as a frequency distribution rather than a single point estimate, flagged as ordinal so the compiling circular does not treat it as a continuous variable.

Estuarine and coastal water quality citizen science

¶1 Estuaries and coastal waterways are ecologically significant transition zones where freshwater and marine systems interact. Citizen science water quality monitoring programs operating in these environments can contribute to ocean accounts but involve institutional and statistical considerations not present in open-marine contexts:

¶2 **Use case:** A national statistics office compiling ocean accounts for a river delta system receives nutrient and turbidity monitoring data from a community water quality network operating across 22 catchment sub-basins flowing into a coastal lagoon. The network has monitored monthly for six years. Official water quality monitoring by the environment agency covers only 4 of the 22 sub-basins. The citizen science data are calibrated against official measurements at overlapping stations (Tier 3 for calibrated stations; Tier 2 for uncalibrated sub-basins) and used to estimate nitrogen loading from the catchment to the coastal lagoon.

¶3 **Decision support:** The nutrient flow accounts combine official and citizen science data. They enable attribution of nitrogen loading by sub-basin and seasonal pattern. Agricultural sub-basins with elevated wet-season nutrient pulses are identified as priority intervention areas. The accounts contribute to the freshwater-marine interaction accounts described in **TG-6.13 Freshwater-Marine Interaction Accounting**.

¶4 **Institutional interface:** Estuarine citizen science programs typically sit at the boundary between freshwater and marine statistics mandates. Compilers should:

- ¶5 Clarify institutional responsibility for estuarine accounts with both freshwater and marine statistics units before compilation begins, to avoid double-counting or gaps at the freshwater-marine boundary.
- ¶6 Apply consistent spatial attribution rules: observations collected at or above the defined tidal limit should be classified as freshwater observations, observations below the tidal limit as

marine observations, and observations at tidal limit monitoring stations as estuarine with dual-system attribution.

- ¶7 Ensure that nutrient flow estimates from citizen science programs are reconciled with any overlapping official estimates in freshwater flow accounts before inclusion in coastal nutrient flow accounts, to avoid double-counting the same nutrient loads.

¶8 These use cases illustrate that citizen science data serve distinct purposes in ocean accounting: gap-filling where official data are sparse, temporal supplementation where official data are infrequent, cost-effective large-scale monitoring for distributed pressures like beach litter, spatial expansion for ecosystem condition assessment, and catchment-to-coast nutrient flow estimation in estuarine systems. In each case, appropriate quality assurance (bias assessment, calibration, validation) and transparent metadata documentation ensure that the data are fit for purpose for the intended decision context.

3.7 Emerging Practices and Future Development

¶1 The field of citizen science and community-based monitoring is changing quickly, with advances in technology, methodology, and institutional frameworks. Statistical offices and accounting practitioners should track emerging developments that may expand the potential for citizen science contributions to ocean accounts.

Technology developments

¶1 Mobile applications, low-cost sensors, and image recognition technologies are making it easier for volunteers to collect and submit observations, while also enabling new forms of quality control⁴³. Environmental DNA (eDNA) sampling, where volunteers collect water samples for laboratory analysis, represents a particularly promising development for marine biodiversity monitoring⁴⁴.

¶2 **eDNA data and the tier framework:** eDNA data derived from volunteer-collected samples are currently restricted to Tier 1 until all three of the following conditions are met:

¶3 (a) The sampling program has a documented chain-of-custody from sample collection to laboratory analysis, including sample preservation, shipping, and receipt records.

¶4 (b) The analytical laboratory holds ISO 17025 accreditation relevant to the analytical methods applied, or has benchmarked its methods against an ISO 17025-accredited laboratory with documented results.

¶5 (c) The eDNA-derived variable (for example, species presence/absence, relative abundance index, or diversity metric) has been mapped to a specific SEEA EA biophysical variable with documented conversion uncertainty, including the uncertainty contribution from reference database coverage.

¶6 Statistical offices should monitor the development of eDNA standards by ISO/TC 147/SC 5 (Water quality – Biological methods subcommittee), which is developing international standards for eDNA methods that may provide the basis for future Tier 2 or Tier 3 qualification.⁴⁵

Methodological advances

¶1 Research is advancing on statistical methods for combining citizen science data with official monitoring data, accounting for known biases and uncertainty⁴⁶. These methods, sometimes termed “data fusion” or “integrated modelling,” may enable more rigorous integration of citizen science data into official accounts over time. Integrated species distribution models, which combine structured survey data with opportunistic citizen science observations within a single statistical framework, have shown particular promise for marine applications. Recent work on occupancy models that account for imperfect detection in volunteer surveys is enabling more reliable estimation of species occurrence and abundance trends from citizen science datasets⁴⁷. As these

statistical methods mature and become more widely adopted, the potential for Tier 3 integration of citizen science data is likely to increase.

Institutional developments

¶1 Some national statistical offices are beginning to explore frameworks for incorporating citizen science and other non-traditional data sources into official statistics⁴⁸. As these frameworks mature, clearer guidance on integration approaches is likely to emerge.

¶2 The SEEA EA *Technical Guidance on Biophysical Modelling* notes that “data quality frameworks developed by statistical agencies currently do not include standards for modelled data. These frameworks should be expanded to encompass the specific quality issues that arise from modelled data”⁴⁹. The same observation applies to citizen science data – existing quality frameworks were developed for traditional data sources and may need adaptation for the specific characteristics of volunteer-collected data.

4. Acknowledgements

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¶2 **Reviewers:** [To be confirmed]

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