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Pacific Region

Canadian Science Advisory Secretariat
Science Advisory Report 2026/049

DATA INPUTS NEEDED FOR THE IDENTIFICATION OF HABITATS OF SPECIAL IMPORTANCE FOR TRANSIENT KILLER WHALES (*ORCINUS ORCA RECTIPINNUS*) IN CANADIAN PACIFIC WATERS



Bigg's killer whales (aka Transient Killer Whales; photo: J.R. Towers).

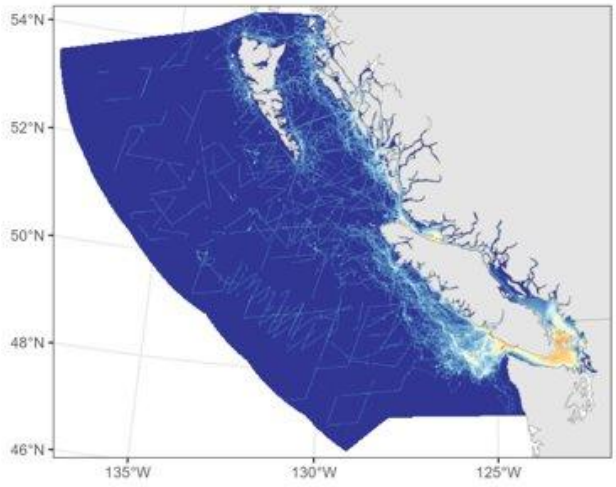


Figure 1. Extent of study area and cumulative visual effort for Transient Killer Whales across sources of visual data (2010-2024).

CONTEXT

Critical habitat is defined under the *Species at Risk Act (*SARA) as "the habitat that is necessary for the survival and recovery of a listed wildlife species and that is identified as the species' critical habitat in the recovery strategy or in an action plan for the species" (SARA s.2(1)). Sections 41(1)(c) and 49(1)(a) of SARA require "an identification of the species' critical habitat, to the extent possible, based on the best available information" for a threatened or endangered species. Critical habitat identification is typically informed by advice provided through a Canadian Science Advisory Secretariat (CSAS) Science Advisory Process, which provides advice on important habitat.

The Recovery Strategy for the Transient Killer Whale (*Orcinus orca rectipinnus*) in Canada provides a schedule of studies necessary to identify critical habitat (Fisheries and Oceans Canada [DFO] 2007). In 2013, science advice identifying areas of special importance to the threatened Transient (a.k.a. Bigg's) Killer Whale in Canadian Pacific waters was provided using data collected up to 2011 (Ford et al. 2013). This advice pertained specifically to those Transients showing the most fidelity to inner coast waters (referred to as 'inner coast Transients' in Ford et al. 2013). A significant amount of Transient Killer Whale data has been collected since 2011, and at the same time there have been improvements in the methods for identifying

important habitats. Accordingly, a new analysis is needed that could allow a gradation or refinement of the habitats of special importance identified in the 2013 science advice.

DFO's Species at Risk Program has requested that Science Branch provide updated advice on habitat of special importance for the Northeast Pacific Transient Killer Whale population (i.e., the designatable unit [DU]), including advice on what geographic area(s) have the appropriate features and attributes to support the life functions required. For the purposes of this request "Transient Killer Whale" is used to refer to the Northeast Pacific Transient Killer Whale population DU. See COSEWIC 2023 for additional details. Due to the large amount of data available and the need for novel modelling frameworks that can integrate multiple data sources, DFO Science has developed a two-phase approach. The first phase will provide a review of the approaches to select, process, and summarize the best available information that will be used as inputs in habitat models. The recommendations and advice produced by this review will inform an anticipated request for identification of habitat of special importance for Transient Killer Whale in the second phase. This second phase is anticipated to consist of modelling frameworks that will be developed and applied to those data inputs to support the identification of critical habitat in an amended SARA recovery strategy for the Transient Killer Whale in Canadian Pacific waters.

This Science Advisory Report is from the regional peer review of May 12-14, 2026 on the Review of Data Inputs Needed for the Identification of Habitat of Special Importance for Transient Killer Whales in Canadian Pacific Waters. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- A two-phase science process was developed to support updated advice on habitats of special importance for Northeast Pacific Transient Killer Whales (TKW) in Canadian Pacific waters. This first phase evaluated available datasets and methods for preparing inputs for subsequent habitat modelling.
- Multiple datasets are needed to understand TKW habitat use. Vessel-based visual observations (e.g., dedicated surveys, whale-watching) and passive acoustic monitoring (PAM) data were selected to represent TKW occurrence. As TKW prey on marine mammals, data on the distribution of pinnipeds and porpoises were used to represent prey availability.
- Data spanning 2010-2024 and encompassing the Canadian Pacific Exclusive Economic Zone and some adjacent U.S. waters were used to characterize a wide range of environmental conditions affecting recent TKW distribution patterns.
- Sampling effort for whale occurrence data was quantified to account for biases and to support future integration into TKW habitat models. Effort associated with systematic and non-systematic vessel surveys was quantified directly from vessel tracks. Effort associated with whale-watch observations and data collected in response to reports of whale presence were modelled and incorporated uncertainty.
- TKW acoustic presence was confirmed from vocalizations across a coastwide array of hydrophones using automated detectors and expert validation. PAM effort was characterized by the detection area and recording schedule of hydrophones, and the performance of automated detectors, while accounting for variability in environmental conditions and uncertainty about TKW vocal behaviour.

- Predicted at-sea availability of pinnipeds was modelled from haul-out survey data, accounting for seasonal variation, sex-specific behaviour, and movement patterns. Existing porpoise density and distribution data require additional consideration.
- This process led to expert consensus on which data to use and how to prepare these diverse datasets for future habitat modeling. Sensitivity analyses and validation are recommended prior to use in TKW habitat models for particular data layers where important uncertainties were identified.

BACKGROUND

Northeast Pacific Transient Killer Whales (TKW; commonly known as Bigg's Killer Whales) are wide-ranging marine predators that use coastal, inland, and offshore waters of the Canadian Pacific Exclusive Economic Zone. Information on their spatial distribution has been collected through a variety of visual and acoustic monitoring programs, including dedicated vessel surveys, opportunistic observations, whale-watch activities, and passive acoustic monitoring (PAM). These datasets differ substantially in spatial coverage, observation methods, and associated detection processes.

A central challenge in the analysis of TKW habitat use is that observed detections reflect both underlying whale distribution and heterogeneous observation effort. Spatial patterns in sightings or acoustic detections may therefore arise from ecological processes, uneven sampling effort, and/or differences in detectability among data sources. Previous habitat assessments were constrained by limited information on observation effort and relied primarily on visual encounter records. Since that time, substantial new datasets have become available, along with analytical approaches that allow explicit characterization of effort and integration of multiple complementary data streams.

The objective of this first phase was to review approaches for selecting, processing, and summarizing available datasets into integrated, model-ready inputs suitable for subsequent habitat modelling. Emphasis was placed on the characterization of sampling effort, acoustic detectability, prey availability, and the development of a common spatial and temporal framework for integrating heterogeneous data sources.

ANALYSIS

Spatial and temporal framework

A common spatial and temporal framework was developed to integrate heterogeneous datasets collected across Canadian Pacific waters. The proposed analytical extent encompassed all waters of the Canadian Pacific Exclusive Economic Zone (Figure 1) and focused on the period from 2010-2024 in order to represent contemporary habitat-use patterns while maximizing overlap among datasets and capturing a broad range of environmental variability, thereby improving robustness of predictions under future conditions. A universal 2x2 km spatial grid was adopted to support integration of visual, acoustic, environmental, and prey datasets within a common spatial framework. Pooling data across all years in the study period for each season was considered appropriate for representing average seasonal spatial patterns in habitat use and for reducing sensitivity to uneven temporal coverage among datasets.

Visual detection datasets and effort characterization

Visual detection information originated from multiple observation processes, including systematic surveys, non-systematic research surveys, whale-watch observations ('platforms of

opportunity'), and detections collected in response to notification networks ('reactive', Figure 2). These datasets differed substantially in spatial coverage, observation methods, and associated biases.

Explicit characterization of sampling effort was considered preferable to treating TKW detections as presence-only data. For systematic and non-systematic surveys, effort was quantified directly from vessel track data. For whale-watch and responder-based detections, effort was modelled to approximate expected spatial patterns while incorporating uncertainty associated with vessel behaviour and killer whale detection processes.

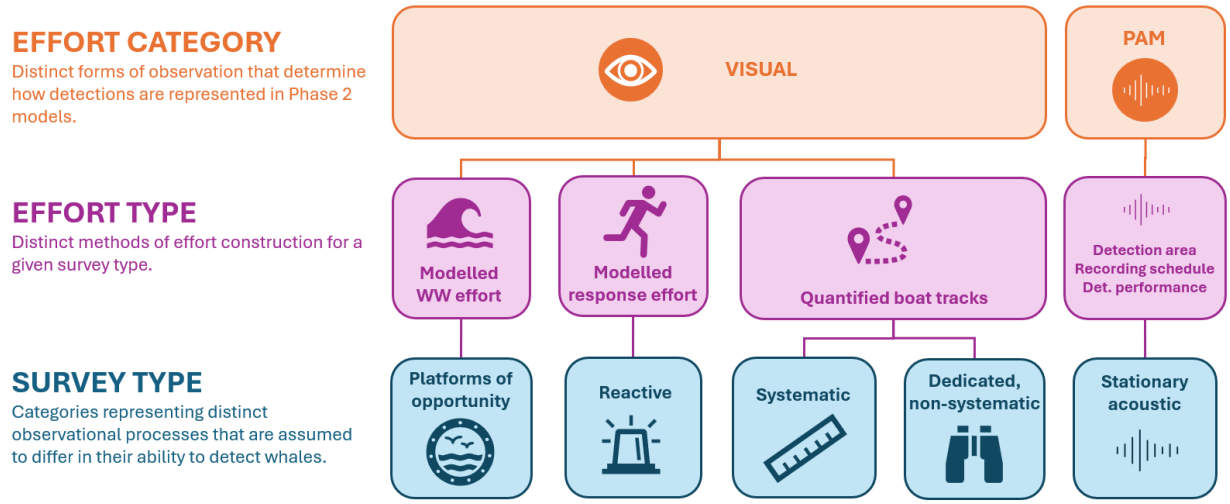


Figure 2. Schematic of survey types and associated effort reconstruction proposed to characterize sampling effort and integrate TKW detections into spatial distribution models for Canadian Pacific waters. "WW" refers to whale watching. "Det." signifies detector.

Passive acoustic monitoring and acoustic effort characterization

Passive acoustic monitoring (PAM) data provided complementary spatial and temporal coverage, particularly in offshore and northern waters and in winter where and when visual effort was limited. TKW acoustic presence was confirmed from ecotype-specific vocalizations recorded across a coastwide array of hydrophones using automated detectors and expert validation (Figure 3).

PAM effort was characterized by the detection area and recording schedule (or 'duty cycle') of hydrophones, and the performance of automated detectors, while accounting for variability in environmental conditions and uncertainty about TKW vocal behaviour. A probability-weighted effective detection area approach was considered an appropriate method for representing spatial variation in acoustic detectability and integrating uncertainty into subsequent analyses. Incorporating the proportion of time recorded and the duration of gaps between recording periods in Phase 2 analyses was considered necessary to adequately account for differences in recording schedules (and therefore detection probability) among PAM sites. Lastly, detector performance was determined an important metric to quantify and incorporate into subsequent analyses, where the methodological approach would require computing false negative rates (i.e., killer whale detections missed by the detection methods) from a representative subset of PAM deployments.

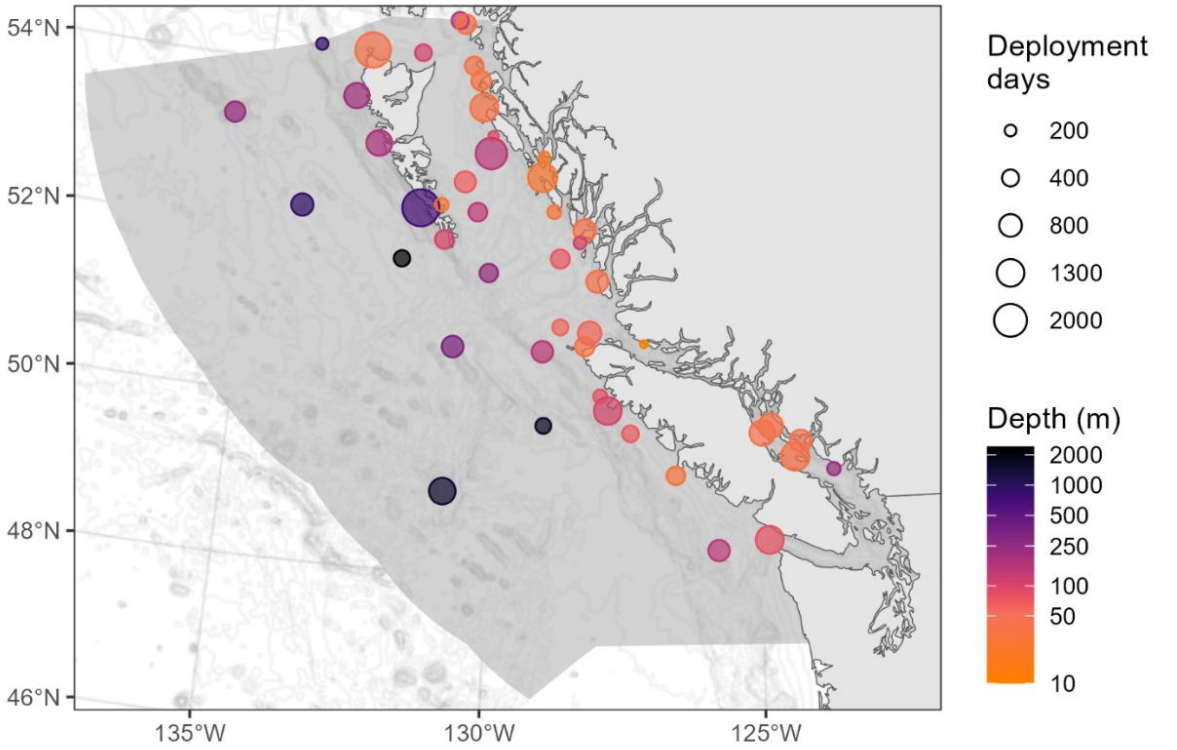


Figure 3. Map of PAM deployment sites from the DFO Cetacean Research Program, where site icons are sized according to their total deployment recording days from 2010-2024 and coloured by the depth at which they were deployed. Note that these represent potentially available PAM data, as not all deployments are currently analyzed. Study domain denoted by translucent grey polygon. Light grey lines represent depth contours.

Environmental and prey covariates

Environmental and prey datasets were reviewed for suitability as inputs in subsequent habitat models. Some covariates were already available in compatible formats. Pinniped prey proxy surfaces for harbour seals (*Phoca vitulina*), Steller sea lions (*Eumetopias jubatus*), and California sea lions (*Zalophus califonianus*) were developed by transforming haul-out survey data into predicted at-sea availability accounting for seasonal variation, sex-specific behaviour, and movement constraints (Figure 4).

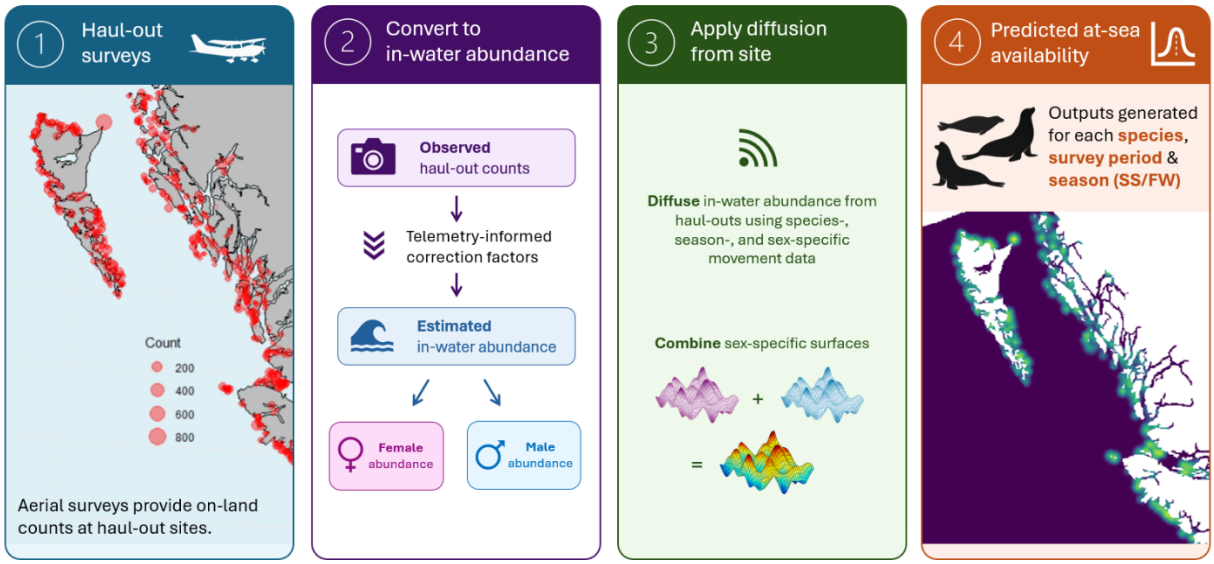


Figure 4. Conceptual workflow for generating predicted at-sea pinniped availability surfaces from haul-out survey data. Final outputs consisted of prediction rasters generated for each species, survey period, and biannual season (spring-summer [SS] and fall-winter [FW]).

Integrated modelling framework

The reviewed approaches were considered to provide a transparent and defensible framework for integrating heterogeneous visual, acoustic, environmental, and prey datasets in subsequent spatial models of TKW habitat use, although some data products were determined to require additional validation, sensitivity testing, or refinement (Table 1).

Table 1. Products presented for review in Phase 1. Status refers to the categorization of the data product as determined by consensus of the CSAS review participants and authors, where A = ready for direct use as a primary analytical input, B = suitable for use with caveats pending targeted validation and sensitivity testing, and C = not currently suitable for primary use; requires substantial validation or refinement. SVI = southern Vancouver Island; NEVI = northeast Vancouver Island.

Product Type	Product	Temporal coverage	Spatial coverage	Status	Next steps	Potential use in habitat models
Presence data	Visual detections (associated with effort)	Full time series, year-round, summer bias	Full domain	A	Possible update with recent sightings	Response for SDM
	Visual detections (presence only)	Full time series, year-round, summer bias	Full domain	C	Possible update with recent sightings	SDM validation?
	PAM detection days	Full time series, year-round	Full domain	A	Continued analysis of priority deployments; potentially adding southern Salish Sea sites	Response for SDM
Visual effort	Standardized boat track effort	Full time series, year-round, summer bias	Full domain	A	Possible update with recent effort	SDM offset/weight
	WW effort emulation	May-Oct	SVI	B	Sensitivity testing of inputs; apply to other regions	SDM offset/weight
	Responder effort emulation	Jun-Oct	NEVI	B	Sensitivity testing of inputs; apply to other regions	SDM offset/weight
	Effort harmonization approach	n/a	n/a	B	Sensitivity testing	SDM offset modifier
PAM effort	Detection area	Full time series	Full domain	A	Model all site-seasons	SDM offset/weight
	Duty cycle metrics	Full time series	Full domain	B	Consider integration approaches	SDM offset/weight
	Detector performance	Full time series	Full domain	B	Sensitivity testing for false negative rates	SDM offset/weight
Prey proxies	Harbour seal (HS) in-water availability	2015-2019, biannual	Full domain	A	Add American data; validation via telemetry data	SDM covariate
	Steller sea lion (SSL) in-water availability	2010-2021, biannual	Full domain	A	Add American data; validation via telemetry data?	SDM covariate
	California sea lion (CSL) in-water availability	2010-2021, biannual	Full domain	A	Add American data; validation via telemetry data?	SDM covariate
	Distance to nearest haul-out (for each HS, SSL, CSL)	Full time series	Full domain	A	Add American data	SDM covariate
	Porpoise density	1. Summer 2018 (PRISMM); 2. Year-round 2020-present (CeMoRe & CeNorth)	1. Full domain; 2. Salish Sea (CeMoRe), north coast (CeNorth)	C	Consider seasonal biases & use of alternative sources for scaling or validation	SDM covariate

Sources of Uncertainty

The approaches reviewed in this process explicitly incorporated and quantified several sources of uncertainty. The following considerations describe additional structural uncertainties and assumptions that may influence interpretation of subsequent habitat modelling results.

No single dataset adequately represented the full spatial distribution of Northeast Pacific TKW in Canadian Pacific waters. Visual encounter data were concentrated disproportionately in inland and nearshore waters in summer months, particularly within regions frequently surveyed by research programs and whale-watch operators, while offshore and wintertime were comparatively underrepresented in visual datasets. Passive acoustic monitoring (PAM) provided complementary coverage in some poorly sampled areas and seasons, but acoustic detections are themselves subject to distinct detection processes and constraints. As a result, some regions and habitat types remain less well represented than others, and uncertainty associated with future spatial modelling is expected to be greater in areas with limited observational coverage.

Although substantial work went into characterizing observation effort across datasets, some components of sampling effort remained imperfectly known. Effort associated with systematic and non-systematic vessel surveys could be quantified directly from vessel tracks, but modelled effort for whale-watch and responder-based detections relied on assumptions regarding vessel behaviour, search patterns, communication among observers, and responses to whale detections. These assumptions may not fully reflect realized search effort in all regions or conditions. As a result, observation effort may still have some remaining influence on predicted whale distribution, despite explicitly accounting for effort and detection processes.

PAM-derived detections were subject to additional uncertainty associated with acoustic detectability and killer whale vocal behaviour. Acoustic detection area modelling incorporated environmental variability, ambient noise conditions, and uncertainty in source levels, but several components of the acoustic detection process remain incompletely characterized. In particular, source levels for TKW are not known and had to be assumed. Moreover, vocal behaviour and calling rates likely vary with behavioural state, group composition, and environmental conditions, and the relationship between acoustic detections and whale presence may therefore vary spatially and temporally. Assumptions associated with acoustic propagation modelling, including representation of geoacoustic conditions and environmental noise, may also influence estimates of acoustic detection area.

Environmental and prey covariates used in subsequent habitat models are also subject to uncertainty. Pinniped prey fields were derived by transforming haul-out survey data into predicted at-sea availability surfaces using assumptions regarding haul-out correction factors, movement constraints, and spatial dispersal. These surfaces represent broad-scale proxy indicators of prey availability rather than direct measures of prey encounter rates or vulnerability to predation. In addition, not all known pinniped prey species of TKW were included in the analysis, and prey distributions likely vary over spatial and temporal scales not fully captured in the available datasets. Though contemporaneous density surfaces for porpoise were already available, they are limited in spatial (DFO 2025) or temporal (Wright et al. 2021) scope and further exploration is required to assess their utility as prey covariates in subsequent habitat modelling (Table 1).

The analytical framework adopted in this process emphasized representation of average spatial patterns in habitat use across the 2010-2024 study period. Temporal aggregation and seasonal stratification were considered appropriate for integrating heterogeneous datasets and reducing sensitivity to uneven temporal coverage; however, this approach does not explicitly capture

interannual variability or shorter-term ecological dynamics. Resulting habitat models are therefore expected to represent broad-scale relative spatial patterns averaged over the study period rather than temporally explicit habitat use in any individual year or season.

CONCLUSIONS

This review evaluated available visual, acoustic, environmental, and prey datasets and led to expert consensus on the approaches proposed to transform these diverse data into integrated inputs for subsequent habitat modelling of TKW in Canadian Pacific waters. No single visual dataset adequately represented the full spatial distribution of TKW in Canadian Pacific waters. Moreover, PAM data provide important complementary information on TKW occurrence. Therefore, combining multiple visual and PAM datasets was considered necessary to reduce bias associated with uneven sampling coverage, and to improve representation of TKW occurrence across the study area and period.

A central conclusion of this review was that explicit characterization of sampling effort and detection processes is necessary to reduce bias associated with heterogeneous data collection methods. Treating TKW detections as presence-only data was considered less appropriate because observed detections reflect both underlying whale distribution and uneven observation effort across regions, seasons, and survey types.

The reviewed approaches for quantifying and modelling observation effort, characterizing acoustic detectability, integrating heterogeneous datasets within a common spatial and temporal framework, and representing prey availability, were considered suitable for informing the second phase of the science process, which will involve development and evaluation of spatial habitat models intended to support updated advice on habitats of special importance for TKW in Canadian Pacific waters. However, additional sensitivity analyses and validation were recommended for particular data layers where important uncertainties were identified.

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SOURCES OF INFORMATION

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