Assessing streambank erosion and riparian characteristics: comparison of field- and imagery-based methods

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Simon S. Vale, Paul G. Peterson.

Bioeconomy Science Institute Maiangi Taiao

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Prepared for: Ministry for the Environment

Reviewed by:

Andrew Neverman
Senior Researcher – Geomorphology / Erosion and Sediment Processes and Research Priority Area Leader
Bioeconomy Science Institute

Approved for release by:

Sam Carrick
Portfolio Leader – Land Resources & Climate Change
Bioeconomy Science Institute

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Summary

Project and client

- The Ministry for the Environment (MfE) contracted the Bioeconomy Science Institute (BSI)[1] to evaluate standardised methods for monitoring streambank erosion protection and riparian condition. This work supports the resource management system reform programme and the development of nationally consistent environmental monitoring.
- The project compared three approaches to monitoring streambank erosion and riparian characteristics: field-based surveys, high-resolution aerial imagery analysis, and standard-resolution aerial imagery analysis. We evaluated the ability of each approach to reliably characterise streambank and riparian condition in terms of accuracy, consistency, practicality, cost, and scalability. The findings identify the strengths, limitations, and most appropriate applications of each approach, providing a foundation for a nationally consistent and operationally practical monitoring framework.

Objectives

- The primary objective of this project was to evaluate and compare alternative methods for monitoring streambank erosion protection and riparian condition to inform the development of a nationally consistent monitoring approach.
- The specific objectives were to:
    - assess the performance of existing monitoring methods, including field-based surveys and desktop-based approaches using aerial imagery
    - compare high-resolution and standard-resolution aerial imagery to determine the added value of higher-resolution data in terms of cost and scalability
    - evaluate these methods against key criteria related to accuracy, repeatability, sensitivity to change, cost, practicality, and scalability
    - identify the strengths, limitations, and appropriate applications of each method, and provide recommendations.

Methods

- Thirty-one stream reaches of c. 500 m were selected from the Hawke's Bay TANK[2] catchments to represent a range of stream sizes, land uses, riparian conditions, and channel characteristics.
- Each site was assessed using three monitoring approaches: field-based surveys, high-resolution aerial imagery (2.5 cm orthophotography with stereo imagery), and standard-resolution aerial imagery (25 cm orthophotography). All three approaches assessed the same streambank and riparian characteristics using a consistent assessment framework, enabling direct comparison between methods.
- Reach-scale estimates of streambank and riparian characteristics derived from each method were compared at all monitoring sites. Agreement between methods was evaluated

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[1] On 1 July 2025 Manaaki Whenua – Landcare Research merged with Plant and Food, AgResearch, and Scion to form the New Zealand Institute for Bioeconomy Science Ltd. Manaaki Whenua – Landcare Research operates as an internal group within this Institute, which has the operating names Bioeconomy Science Institute Maiangi Taiao or Bioeconomy Science Institute (BSI).

[2] TANK: Tūtaekurī, Ahuriri, Ngaruroro, and Karamū

using mean difference, mean absolute error, root mean square error, correlation coefficients, and paired *t*-tests. These comparisons were complemented by evaluation of repeatability, implementation requirements, operational considerations, cost, scalability, and suitability for regional and national monitoring programmes.

Results

- The three monitoring approaches exhibited distinct strengths and limitations. Field surveys provided the greatest observational detail, high-resolution aerial imagery offered the best overall balance between information content, repeatability, implementation effort, and scalability, while standard-resolution imagery provided the lowest implementation effort and generally the lowest implementation costs as suitable imagery was already available from regional imagery acquisitions, so bespoke capture was not required.
- Monitoring performance primarily depended on the riparian characteristic being assessed. Structural characteristics with clearly defined spatial extent, including fencing extent, woody vegetation, riparian vegetation width, and overall stream shading showed strong agreement between methods. In contrast, characteristics requiring more subjective interpretation of condition or subtle disturbance, such as fence effectiveness, streambank erosion, stock pugging, and the presence and nature of obstructions, were less consistently assessed, especially from low-resolution aerial imagery. Monitoring performance also declined where visibility was restricted by dense riparian vegetation, canopy cover, or other physical obstructions that limited observation.
- High-resolution aerial imagery required no field effort while producing a permanent, spatially referenced record that improves repeatability, transparency, and quality assurance, and provides opportunities for future semi-automated monitoring. Standard-resolution imagery remained well suited to broad-scale assessments where extensive spatial coverage or low implementation costs were priorities, but provided lower confidence for fine-scale streambank and riparian characteristics.

Conclusions

- Each monitoring approach exhibited distinct strengths and limitations. The most appropriate method depends on the objectives of the monitoring programme and the streambank or riparian characteristics being assessed.
- High-resolution aerial imagery provided the best overall balance between information content, repeatability, operational efficiency, and scalability. It is well suited to routine monitoring of structural riparian characteristics, but field surveys remain the preferred approach for assessing condition, disturbance, and other fine-scale characteristics requiring direct observation.
- The optimal monitoring approach taken will require balancing information requirements, implementation costs, scalability, and available resources against the objectives of the monitoring programme. This study provides an evidence base to inform those decisions but does not prescribe how these competing considerations should be prioritised.
- Future research should explore dedicated imagery-based frameworks that integrate aerial imagery, complementary spatial data sets, automated feature extraction, and targeted field verification. Such approaches have the potential to improve consistency, efficiency, scalability, and national reporting while retaining field surveys for characteristics that cannot yet be reliably assessed from remotely sensed data.

Recommendations

- *Consider high-resolution aerial imagery as the primary monitoring approach*. High-resolution aerial imagery provides the strongest overall balance between information content, repeatability, implementation effort, and scalability for regional state of the environment monitoring. Targeted field surveys should complement imagery where direct observation is required, or where visibility is limited by canopy cover or other obstructions. The final monitoring approach taken should balance information requirements, implementation costs, scalability, and available resources in the context of the monitoring and policy framework.
- *Continue validation and refinement*. Future work should focus on simplifying monitoring protocols, prioritising high-value characteristics, and validating the approach across a wider range of regions, stream types, land uses, and environmental conditions to support robust national implementation.
- *Integrate complementary spatial data sets and emerging technologies*. Future monitoring should increasingly integrate aerial imagery with complementary spatial data sets, including LiDAR and canopy height models, together with object-based image analysis, machine learning, and artificial intelligence to support more consistent, efficient, and semi-automated monitoring.

1 Introduction

The Ministry for the Environment (MfE) contracted the Bioeconomy Science Institute Maiangi Taiao (BSI) to investigate standardised methods for monitoring streambank erosion protection and riparian condition. This project forms part of the resource management system reform programme and aligns with MfE's strategic priorities to improve the efficiency and effectiveness of this system, improve the quality and accessibility of evidence for decision-making, and support partnerships that enable environmental outcomes that have a real impact.

Under the proposed Natural Environment Act (NEA), environmental limits are intended to protect the life-supporting capacity of natural resources and safeguard human health. A key requirement for limit-setting is the use of measurable attributes that can be robustly and feasibly monitored over time. Streambank erosion protection and riparian condition are recognised as important attributes influencing soil loss and sediment delivery to waterways, water quality, habitat condition, and overall riparian and river health. However, there is currently no nationally consistent approach to monitoring these characteristics. Regional councils use a range of monitoring methods that reflect differing objectives, resources, and operational contexts. While these approaches are often fit-for-purpose locally, the resulting variability presents challenges for consistency, comparability, and implementation within a national monitoring and limit-setting framework.

This project is a first step towards evaluating whether streambank erosion and riparian condition could be considered as a quantitative attribute within the future environmental limits framework. A prerequisite for any attribute is that it can be measured consistently, robustly, and feasibly over time. Accordingly, the focus of this project is on assessing monitoring approaches rather than establishing environmental limits themselves. Further work would be required to determine whether streambank erosion and riparian condition are suitable for inclusion as a formal attribute for environmental limits.

To support this objective, the project undertakes a comparative assessment of three monitoring approaches: field-based surveys, high-resolution aerial imagery analysis, and standard-resolution aerial imagery analysis. The assessment evaluates the ability of each approach to reliably characterise streambank erosion protection and riparian condition, while also considering factors such as accuracy, consistency, cost, practicality, and scalability. The aim is to identify the strengths and limitations of each method and to determine where individual approaches, or combinations of approaches, are most suitable for implementation. The findings will help inform the development of a nationally consistent, robust, and operationally practical framework for monitoring streambank erosion and riparian condition.

2 Background

2.1 Streambank erosion and riparian condition

Erosion of stream banks is a natural geomorphic process as channels adjust their size, shape, and position in response to water and sediment fluxes. A wide variety of fluvial and mass movement processes contribute to streambank erosion, including processes such as fluvial scour, bank undercutting, mass failure, and lateral channel migration, which are all important components of sediment transport within river systems (Watson & Basher 2006). While streambank erosion is a natural part of river evolution (Florsheim et al. 2008), rates can be substantially accelerated by human-induced changes to catchment hydrology, channel form, riparian vegetation, and land use (Brooks & Brierley 1997; Hughes 2016; Smith et al. 2019).

Historical vegetation clearance, agricultural development, stock access, and channel modification have altered channel and riparian conditions in many catchments, often increasing streambank susceptibility to erosion. In New Zealand, streambank erosion is recognised as a major source of sediment to waterways, alongside surface erosion and mass-movement processes such as landslides, gullies, and earthflows (Basher 2013). Although mass-movement processes typically dominate sediment production over multi-decadal timescales, streambank erosion can contribute a substantial proportion of suspended sediment loads in some catchments, and because it occurs adjacent to channels, delivers sediment directly to waterways.

Despite its importance, streambank erosion remains one of the least understood and least quantified components of catchment sediment budgets (Basher et al. 2012; Basher 2013; Smith et al. 2019). This reflects the complex and spatially variable nature of bank erosion processes, their episodic occurrence during high-flow events, and the challenges of measuring erosion rates and sediment contributions at catchment scales (Hughes et al. 2022). Although relatively few studies have quantified the contribution of streambank sediment in New Zealand, reported estimates range from streambank erosion being a negligible to dominant source of suspended sediment (e.g. De Rose 1999; McDowell & Wilcock 2007; De Rose & Basher 2011; McDowell et al. 2016; Vale et al. 2016; Vale, Fuller et al. 2020; Vale, Smith et al. 2020; Hughes et al. 2021). This variability reflects differences in catchment characteristics, the period of measurement, and the relative importance of other erosion processes, but demonstrates that streambank erosion can be a significant – and in some cases dominant – source of suspended sediment.

Excessive streambank erosion can have important environmental, economic, and social consequences. Increased sediment delivery can reduce visual clarity, increase sediment deposition, degrade aquatic habitat, and adversely affect freshwater ecosystem health (Owens et al. 2005; Davies-Colley et al. 2015). Streambank erosion can also result in the loss of productive land, damage to infrastructure and wāhi tapu, and increased management costs. Consequently, there is a strong interest in understanding the factors that influence streambank stability and in developing management approaches that reduce sediment inputs and improve freshwater outcomes.

Riparian zones are transitional areas (ecotones) between terrestrial and aquatic ecosystems. They influence the movement of water, sediment, nutrients, and organic matter between hillslopes and waterways (Figure 1). As the interface between land and water, they perform a range of ecological, hydrological, and geomorphic functions that contribute to freshwater ecosystem health. Riparian vegetation can stabilise streambanks, filter sediment and contaminants from run-off, regulate stream temperatures through shading, provide habitat and movement corridors for indigenous species, and support ecological connectivity between terrestrial and aquatic environments (Collier et al. 1995; Davies-Colley et al. 2004; Clerici et al. 2011; Parkyn 2004; Lawton et al. 2026).

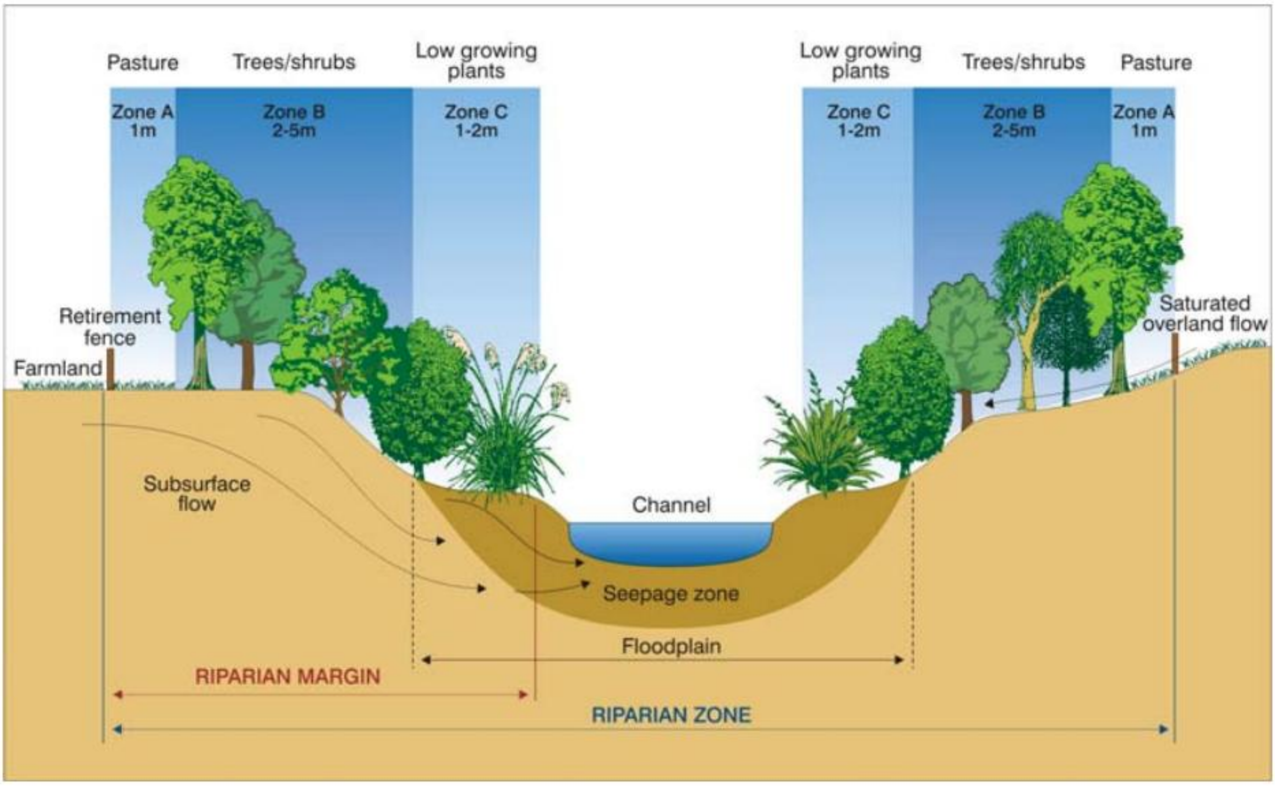

Figure 1. A conceptual representation of riparian zone components, illustrating the riparian margin, floodplain, channel, and vegetation zones. (Source: Taranaki Regional Council 2010)

The condition of riparian zones is closely linked to streambank stability and erosion protection. Riparian vegetation helps maintain bank integrity through root reinforcement, protection from rainfall and overland flow, and resistance to physical disturbance. Conversely, the removal or degradation of riparian vegetation can increase bank erodibility and accelerate erosion processes. Livestock access can further exacerbate streambank erosion through trampling, vegetation removal, soil compaction, and direct disturbance of channel margins. As a result, stock exclusion and riparian planting are widely recognised as key management practices for improving streambank stability, reducing sediment inputs, and enhancing freshwater ecosystem health (Parkyn 2004; Basher 2013; McKergow et al. 2016).

The importance of riparian management is reflected in New Zealand's freshwater policy framework and catchment management programmes. Regional councils, industry groups, and landowners have invested substantially in riparian fencing and planting to improve water quality, freshwater habitat, and streambank stability (e.g. the Sustainable Dairying: Water Accord and various regional council initiatives). The Essential Freshwater reforms introduced national stock exclusion requirements for many waterways (Ministry for the Environment & Ministry for Primary Industries 2019; New Zealand Government 2020), but these requirements provide only a minimum level of protection and do not prescribe riparian vegetation condition, width, or broader ecological outcomes. Also, no single riparian setback width can optimize all riparian functions, with narrower margins often sufficient for stock exclusion and bank protection, while wider setbacks will better intercept sediment and nutrients, regulate stream temperatures, and support habitat and ecological connectivity (Parkyn 2004; McKergow et al. 2016; Fenemor & Samarasinghe 2020; Murfitt 2023).

Monitoring the condition of streambanks and riparian zones supports the identification of land-use impacts, assessment of management effectiveness, and evaluation of environmental outcomes. Several approaches are currently used throughout New Zealand, including field-based surveys, aerial imagery, and other remote-sensing methods. However, these approaches often use different indicators, classifications, and reporting frameworks, resulting in inconsistencies in how streambank erosion and riparian condition are assessed and reported. This variation limits the ability to compare results between regions, evaluate trends at a national scale, and support consistent policy implementation (Phillips 2024). Consequently, there is a need to better understand the trade-offs between monitoring approaches, including their accuracy, repeatability, cost, scalability, and requirements for practical implementation. This project addresses this need by evaluating three approaches and assessing their comparability, strengths, limitations, and suitability for regional and national application.

2.2 Monitoring approaches

In New Zealand different methods are used to monitor streambank erosion and riparian condition. These methods differ in the indicators assessed, level of detail obtained, spatial coverage, cost, and operational requirements. They can be broadly grouped into field-based surveys and remote-sensing.

Field-based surveys are the most direct method for assessing streambank and riparian condition. Trained field teams assess stream reaches using standardised protocols to record attributes such as riparian vegetation cover and structure, streambank stability, erosion extent, stock access, fencing, and management interventions. Waikato Regional Council (WRC) operates one of the longest-running and most comprehensive riparian monitoring programmes in New Zealand, with surveys first undertaken in 2002 and repeated approximately every 5 years (see Storey 2010; Jones et al. 2016; Norris et al. 2020, 2025). The approach provides a consistent data set for assessing riparian condition, spatial variability, and temporal trends. However, field surveys are labour-intensive, require site access and landowner permissions, and can be challenging to implement across large regions.

Remote-sensing methods have increasingly been adopted to address some of the logistical constraints associated with field surveys and to support more efficient, regional-scale monitoring programmes. Several regional councils incorporate GIS-based recording and desktop assessment in their riparian monitoring programmes, although the sophistication and consistency of these systems vary considerably (Manderson 2018). Hawke's Bay Regional Council (HBRC), for example, has transitioned from field-based assessments to desktop assessments using high-resolution aerial imagery (Ireland 2025). This aerial imagery method was originated and developed by Dr Barry Lynch for HBRC (Wu et al. 2019). This approach uses 2.5 cm four-band orthophotography, which can be viewed in 2D or 3D (stereo) to assess riparian vegetation extent and type, fencing, streambank erosion, and other observable attributes within a GIS environment. The addition of stereo imagery enables pairs of overlapping aerial photographs to be viewed stereoscopically, providing a three-dimensional perspective of the landscape that more closely resembles field perception of physical features. However, it relies on the availability of high-resolution overlapping imagery and requires specialist software and hardware.

Standard-resolution (25–30 cm) aerial imagery was also included as an alternative to high-resolution imagery because of its widespread availability and substantially lower direct acquisition costs, as imagery is often already available through existing regional council, Land Information New Zealand (LINZ), or commercial aerial imagery programmes. It therefore has the potential to support large-scale assessments where extensive spatial coverage, cost efficiency, and scalability are prioritised.

Although a variety of other riparian monitoring approaches are used throughout New Zealand, there are substantial differences among regional councils in objectives, indicators collected, and survey protocols, limiting opportunities for consistent regional and national reporting (Manderson 2018). Although most regional councils undertake some form of riparian monitoring, much of this is associated with one-off auditing or programme implementation (e.g. Taranaki's monitoring approach via farm plans), with relatively few councils undertaking regular repeat surveys capable of assessing long-term change (Manderson 2018). Previous reviews have therefore identified considerable scope for greater standardisation of riparian monitoring and reporting, including the development of common indicators and nationally consistent monitoring approaches.

This study focused on field surveys, high-resolution aerial imagery, and standard-resolution aerial imagery because they represent the principal approaches currently available for assessing streambank and riparian characteristics over large spatial extents, and they have the greatest potential to support a nationally consistent monitoring framework. Comparing these approaches provides an opportunity to evaluate the trade-offs between information content, repeatability, practicality, cost, and scalability, and to identify the most appropriate applications for each monitoring method within regional and national monitoring programmes.

3 Objectives

The primary objective of this project was to evaluate and compare methods for monitoring streambank erosion and riparian condition to inform the development of a nationally consistent monitoring approach.

The specific objectives were to:

- assess the performance of existing monitoring methods, including field-based surveys and desktop-based approaches using aerial imagery
- compare high-resolution (including stereo) and standard-resolution aerial imagery to determine the added value of higher-resolution data relative to cost and scalability
- evaluate methods against key criteria related to accuracy, repeatability, sensitivity to change, cost, practicality, and scalability
- identify the strengths, limitations, and appropriate applications of each method.

Although this project does not define environmental limits, it is designed to support future limit-setting by determining whether streambank erosion and riparian condition can be reliably monitored at appropriate spatial and temporal scales.

4 Methods

4.1 Study design

We used a comparative study design to evaluate approaches for monitoring streambank erosion and riparian characteristics. Three monitoring methods were assessed:

- *field-based surveys*, involving direct, on-site assessment of streambank and riparian characteristics

- *high-resolution aerial imagery assessments*, using 2.5 cm orthophotography (including stereo) imagery to remotely assess streambank and riparian characteristics
- *standard-resolution aerial imagery assessments*, using widely available 25 cm aerial imagery to assess the same streambank and riparian characteristics using standard GIS.

Our primary comparison was between field-based surveys and high-resolution aerial imagery assessments. High-resolution imagery was used as the primary imagery-based assessment because it provides the highest level of spatial detail of the approaches evaluated, allowing the extent to which desktop assessments could reproduce observations obtained during field surveys to be assessed. We also included standard-resolution imagery to investigate the influence of image resolution on monitoring outcomes, and to determine whether more widely available imagery could provide a practical alternative where high-resolution imagery is unavailable or prohibitively expensive.

We compared the ability of each method to consistently assess key streambank and riparian characteristics, including streambank erosion, stock exclusion fencing, riparian vegetation, and stream shading. We evaluated each method against a common set of criteria, including agreement, repeatability and consistency, sensitivity to differences in riparian condition, practicality of implementation, operational requirements, and overall suitability for regional and national monitoring programmes.

We selected sites from catchments within the Hawke's Bay Region where high-resolution orthophotography was available. Each site consisted of an approximately 500 m stream reach and its associated riparian corridor. The sites were selected to encompass a broad range of environmental settings, including variation in land use, stream size, channel morphology, streambank condition, and riparian management, within the constraints of the area where high-resolution orthophotography was available.

We developed the study design through an initial stakeholder workshop involving MfE and regional council staff. Early development also included some discussion with colleagues from the New Zealand Institute for Earth Sciences.

4.2 Study area and site selection

We selected study sites from an initial pool of 85 candidate locations within the HBRC TANK catchments (Tūtaekurī, Ahuriri, Ngaruroro, and Karamū). Candidate sites were restricted to areas where recent 2.5 cm orthophotography imagery was available, reflecting the limited spatial availability of high-resolution imagery across the region. Although the TANK programme encompasses four catchments, no sites were selected from the Ahuriri catchment. The target sample size was 25 sites; however, a larger pool of candidate sites was identified to allow for landowner permission, access constraints, and potential site substitutions.

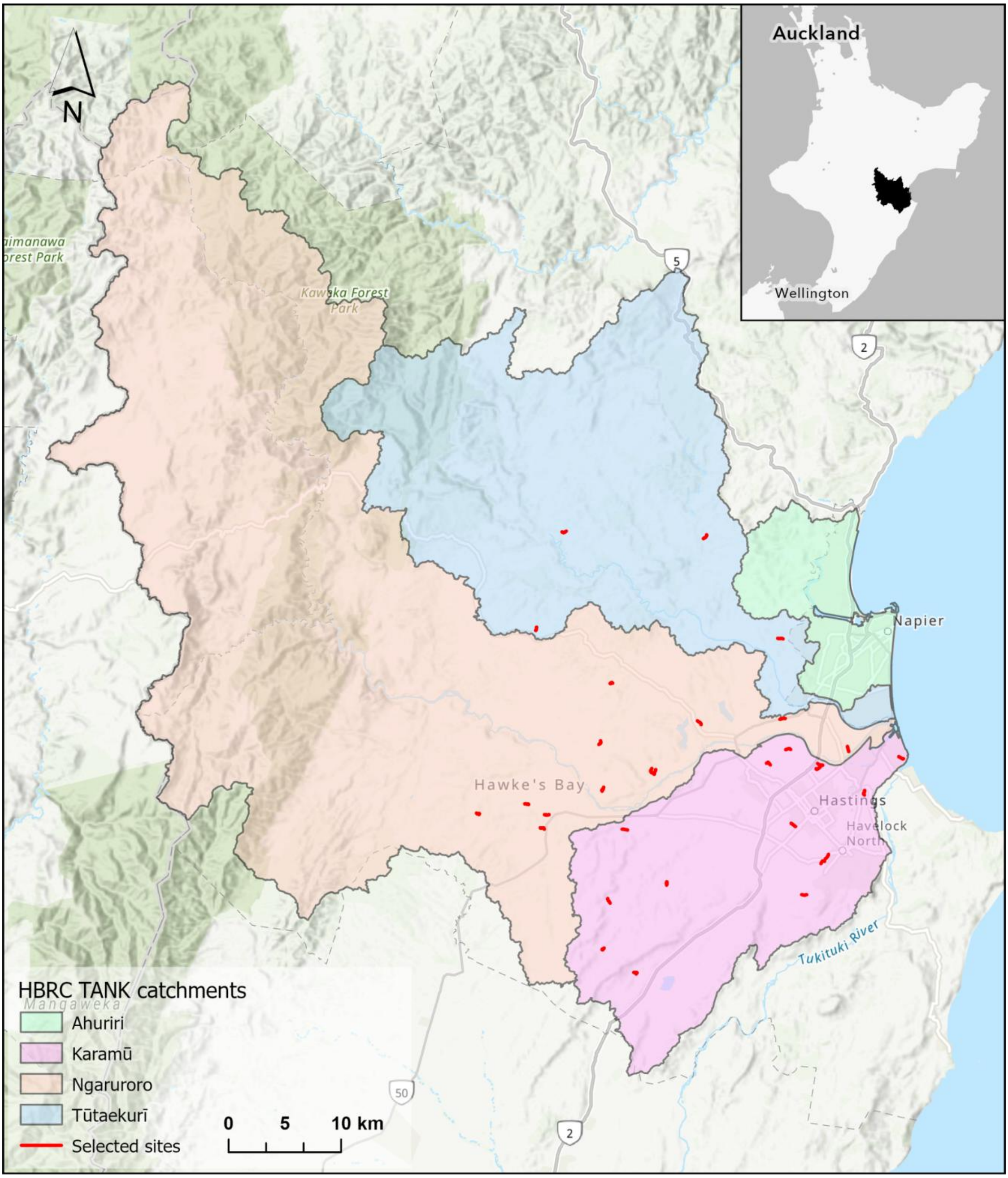

Figure 2. Distribution of the 31 sites selected from the Hawke's Bay Regional Council TANK catchments for evaluating methods of monitoring streambank erosion and riparian condition.

A stratified random sampling design was initially considered, but was considered impractical given the project time frame and resources available for field surveys. Instead, we adopted a semi-stratified sampling approach, whereby candidate sites were selected to provide representation across a range of stream orders, surrounding land uses, and riparian conditions, while also considering practical constraints such as accessibility and travel time. This targeted sampling approach was considered appropriate because the objective of the study was to compare monitoring methods rather than estimate regional condition or produce statistically representative estimates of streambank erosion or riparian condition.

The final data set comprised 31 monitoring sites distributed across the three catchments and encompassing a broad range of stream sizes, riparian conditions, and surrounding land uses. Although the resulting site network was not statistically random, the final selection retained a similar distribution of land-use classes and stream orders to the original pool of 85 candidate sites, indicating that it remained broadly representative of the candidate population. The selected sites also captured a wide range of stream and riparian conditions typically encountered within lowland pastoral and horticultural landscapes, providing an appropriate basis for comparing the performance of alternative monitoring methods across a diverse range of environmental settings.

4.3 Data collection

We visited WRC and held discussions with HBRC to understand how they implement the field-based and desktop methods. We used comparable equipment and software to ensure methods could be implemented consistently. We applied each monitoring method to the same set of study reaches to enable direct comparison of streambank and riparian characteristics derived from field surveys and aerial imagery assessments. Desktop analysis of aerial imagery was completed before the field visits to alleviate concerns that a detailed knowledge of on-ground conditions would influence the desktop analysis (see section 5.1 for further discussion).

Although the two methods originated from a common survey protocol, they had slight differences. The field survey approach collects information in three components: general site information; point characteristics collected at the start, middle and finish of the reach; and continuous streambank and riparian characteristics along both left and right streambanks (Table 1). The imagery-based methods collect general site information and continuous streambank assessments, but not point observations. The continuous streambank assessment was relatively consistent across the approaches, requiring only minor alignment of variable names and classification categories during data processing. Detailed characteristic lists, definitions, and classification rules are provided in Appendices 1 and 2.

Table 1. Summary of the information and characteristics recorded during the field survey, grouped by data category

Data category	Characteristics collected
General site information	Site ID, sampling date, farm type, land use, stream name, stream permanence, break-feeding, site notes
Point observations (start, middle, finish)	Location, bank shape, bank slope, bank height, channel type, channel width, streambed type, valley width, sedimentation, aquatic vegetation, livestock access type
Continuous streambank observations	Land use, fence type, fence status, vegetation type, vegetation width, woody vegetation extent, stream shading, stock access, pugging, streambank erosion, erosion severity, channel obstruction/access type, channel obstruction/access length

Imagery-based assessments record the general site information and continuous streambank observations but not the representative point observations. See Appendices 1 and 2 for descriptions of the assessed characteristics and guidance on their assessment.

4.3.1 Field-based riparian survey method

We undertook field surveys using a standardised, reach-based protocol adapted from the WRC riparian characteristics survey methodology (Storey 2010; Jones et al. 2016; Norris et al. 2020). Field data were collected using a customised ESRI ArcGIS Survey123 data-entry form on a tablet, paired with a Trimble DA2 Global Navigation Satellite System (GNSS) receiver operating with a Trimble Catalyst 60 subscription, providing an expected horizontal positional accuracy of approximately 0.6 m under suitable satellite reception conditions.

Each survey comprised an approximately 500 m stream reach. Starting at the upstream end of the reach, we traversed the riparian corridor on foot from upstream to downstream, generally remaining on one side of the stream, but changing sides where necessary to maintain access or improve visibility. We recorded general site information at the start of each reach, with representative point observations collected at the start, midpoint, and end (Table 1). Continuous streambank characteristics were recorded at the starting point and subsequently whenever a monitored characteristic changed on either the true left or true right bank (Figure 3). We recorded observations only where characteristics changed, enabling the reach to be subdivided into segments of relatively uniform condition while minimising unnecessary observations.

Figure 3. Field assessment of streambank and riparian characteristics. Surveyors walked the stream reach recording georeferenced observations of streambank erosion, riparian vegetation, fencing, stock access, and other riparian characteristics.

We recorded additional observations to mark locations where the channel changed direction substantially or where the channel alignment could not be followed because of access constraints (e.g. dense vegetation). These supplementary points were used during post-processing to maintain a general representation of the channel planform. Where changes in streambank characteristics were identified after passing a location, we either returned to record the observation or documented its approximate location in the survey comments so that it could be incorporated during post-processing.

Following fieldwork, the survey data underwent quality assurance and minor GIS post-processing. This included reviewing observations, correcting point sequencing (essential for calculating chainage, the cumulative along-channel distance from the start of the survey reach, between observations), and refining the channel alignment using the supplementary observations. The ordered observation points were then used to calculate segment chainages using custom R scripts originally provided by WRC and subsequently adapted for this study, from which reach-scale metrics were derived for each monitored characteristic. These metrics formed the basis of the comparison with the imagery-based monitoring methods.

4.3.2 High-resolution aerial imagery assessments

We undertook high-resolution aerial imagery assessments using a GIS-based desktop mapping workflow adapted from the HBRC riparian monitoring methodology (Ireland 2025). Assessments were completed using 2.5 cm orthophotography with overlapping nadir images for stereo imagery supplied by HBRC (Figure 4). The imagery was georeferenced and orthorectified by HBRC prior to assessment, enabling both plan view interpretation and three-dimensional visualisation of streambank and riparian characteristics.

Stereo imagery was viewed using synchronised overlapping image pairs within ArcGIS Pro and a dedicated stereoscopic workstation comprising a dual-screen 3D PluraView monitor and active shutter glasses (Figure 5). This provided a three-dimensional perspective of the stream corridor, allowing for improved interpretation of characteristics that rely on contour and height.

Each stream centreline was digitised within ArcGIS Pro before streambank and riparian characteristics were interpreted visually using the ortho and stereo imagery. The general site information and continuous streambank assessment characteristics described in Table 1 were also recorded. A new streambank segment was digitised whenever a monitored characteristic changed on either the true left or true right bank, creating a series of continuous streambank segments consistent with the field survey approach.

Following digitisation, the high-resolution imagery assessments underwent quality assurance by a second observer to verify interpretation, ensure consistency between sites, and remove any duplicated or overlapping segments that can occur during editing. We then calculated streambank segment lengths and summarised to derive reach-scale metrics as a comparison for those generated from the field survey. Applying an identical processing framework ensured that comparisons between imagery-derived assessments and field observations reflected differences in interpretation rather than differences in data processing.

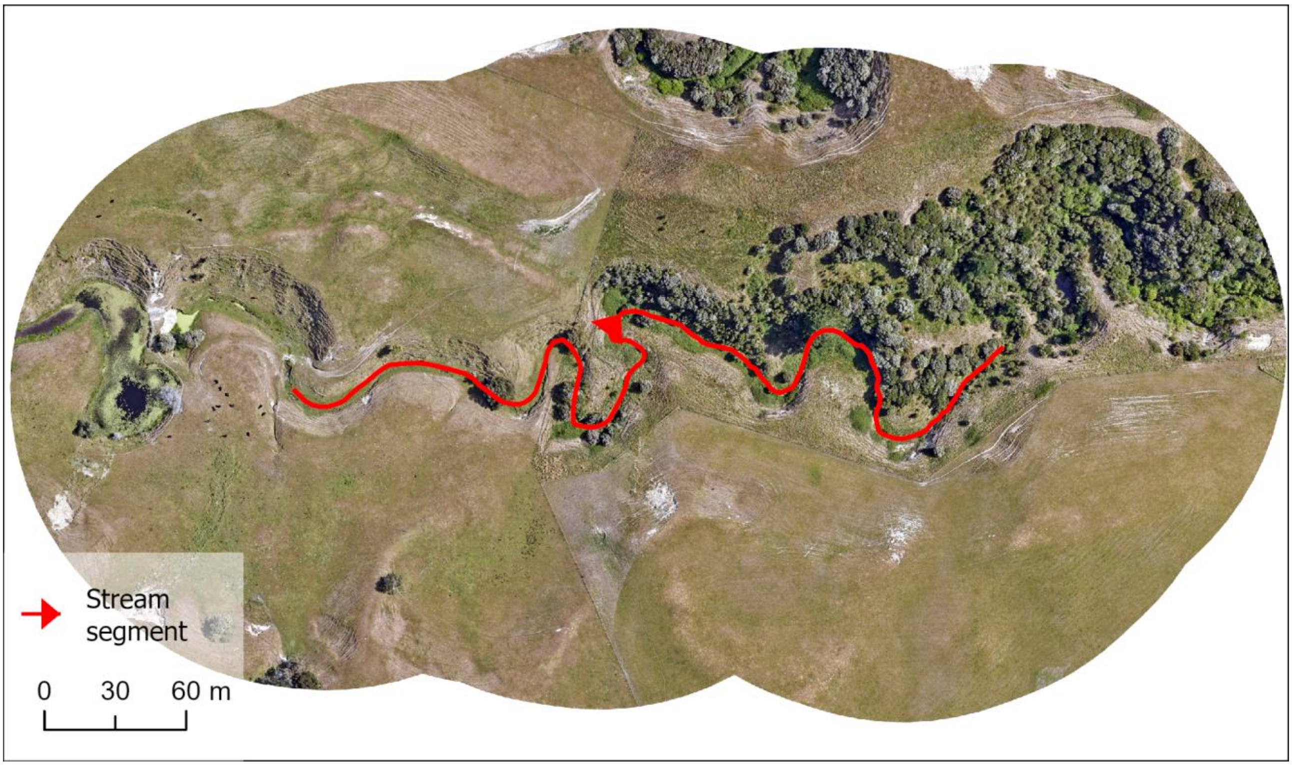

Figure 4. Example of the 2.5 cm high-resolution orthophotography used for desktop assessment of streambank and riparian characteristics. The red line indicates the surveyed stream reach used for the imagery assessment, and the arrow shows the direction of flow.

Figure 5. Example of the stereoscopic workstation used for desktop interpretation of overlapping aerial photographs. A dual-screen 3D PluraView display, dedicated graphics hardware, and active shutter glasses provided a three-dimensional view of the stream. (Source: adapted from https://www.geospatialnext.org/workstation-for-gis-and-mapping/)

4.3.3 Standard-resolution aerial imagery assessments

Standard-resolution aerial imagery assessments were undertaken using the same GIS-based desktop mapping workflow as the high-resolution imagery assessments. Imagery comprised commonly available, regional-scale rural aerial photography taken between February 2023 and February 2025,[3] with a spatial resolution of 25 cm (0.25 m ground sample distance; GSD), which is representative of imagery routinely available for regional council monitoring programmes (Figure 6).[4] Although Hawke's Bay has more recent 12.5 cm (0.125 m GSD) rural imagery, the 25 cm imagery was used because it is more representative of the spatial resolution or rural imagery typically available across New Zealand.

We assessed each survey reach using the same stream extent of 500 m, segmentation approach, and classification framework (Table 1). Segments from the high-resolution assessment were retained as a starting point, and the assessor checked to see whether characteristics could still be seen in lower-resolution imagery. Where characteristics could not be interpreted with sufficient confidence they were recorded as unobserved (null) rather than inferred. Unlike the high-resolution assessments, interpretation relied solely on orthophotography because stereo imagery was not available. Following digitisation, the low-resolution imagery assessments underwent quality assurance, as was done with the high-resolution assessments.

Figure 6. Example of the 25 cm standard resolution orthophotography used for desktop assessment of streambank and riparian characteristics. The red line indicates the surveyed stream reach used for the imagery assessment and the arrow shows the direction of flow.

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[3] https://data.linz.govt.nz/layer/122218-hawkes-bay-025m-rural-aerial-photos-2023-2025/

[4] https://www.linz.govt.nz/products-services/data/types-linz-data/aerial-imagery

4.4 Evaluation framework

The three monitoring approaches were evaluated using a combination of quantitative comparisons and qualitative assessment. Quantitative analyses compared streambank and riparian characteristics derived from the field survey, high-resolution aerial imagery, and standard-resolution aerial imagery, while qualitative assessment considered the interpretation, implementation, and overall suitability of each approach for regional monitoring programmes. The evaluation framework comprised the following four components:

- *agreement between monitoring methods* – a quantitative comparison of streambank and riparian characteristics derived from the three monitoring approaches
- *interpretation of monitoring performance* – an evaluation of the factors influencing agreement, including repeatability, consistency of interpretation, and the ability of each method to differentiate riparian condition
- *practical implementation* – a comparison of the resource requirements, operational considerations, and technical requirements associated with each monitoring approach
- *synthesis of monitoring performance* – integration of the quantitative and qualitative findings to evaluate the relative strengths, limitations, and most appropriate applications of each monitoring approach.

Field surveys provided the most direct observations of site conditions and were therefore used as a best-estimate comparative benchmark for agreement statistics. However, no monitoring method was assumed to represent a universal reference standard. Field observations were considered the most reliable representation of characteristics requiring direct observation, such as fence effectiveness, streambank erosion, stock pugging, and the presence/nature of channel obstructions (such as non-living debris, willows, dams). Conversely, characteristics describing spatial extent, continuity, or riparian width may be estimated as consistently – or in some cases more consistently – from an aerial perspective. Consequently, the evaluation focused on identifying the monitoring approach most appropriate for each streambank and riparian characteristic rather than determining a single 'best' method. However, vegetation can be an overriding factor if aerial visibility is significantly compromised.

Quantitative comparisons were undertaken for the streambank and riparian characteristics and are presented in four attribute groups:

- fencing and stock exclusion (fence presence, fence effectiveness, stock access)
- riparian vegetation (vegetation type, vegetation width, woody vegetation extent, shading)
- streambank erosion and stock pugging
- channel obstructions.

4.4.1 Agreement between monitoring methods

For each monitoring approach we derived site-level summaries for all streambank and riparian characteristics. Regional summaries were calculated as the mean of the 31 site-level estimates, with uncertainty expressed as 95% confidence intervals.

We compared continuous streambank and riparian characteristics between field and imagery-based methods using:

- mean difference (imagery − field survey)

- paired *t*-tests to determine whether the mean difference differed significantly from zero
- mean absolute error (MAE)
- root mean square error (RMSE)
- Pearson's correlation coefficient (*r*)
- scatterplots with a 1:1 reference line.

Mean differences were tested using paired *t*-tests because the same monitoring sites were assessed using each method. Where multiple paired comparisons were undertaken for related indicators, *P* values were adjusted using the Holm method to control the family-wise error rate. This reduced the likelihood of falsely identifying statistically significant differences due to the large number of simultaneous comparisons.

These analyses were used to evaluate agreement between methods, quantify differences in imagery-derived estimates relative to field surveys, identify characteristics that could be reliably assessed using aerial imagery, determine where image resolution influenced interpretation, and identify characteristics that remained better suited to field-based assessment.

4.4.2 Interpretation of monitoring performance

Repeatability and consistency

We qualitatively evaluated repeatability and consistency by considering the extent to which each monitoring approach relied on assessor judgement, the clarity of attribute definitions, the permanence of the data source, and the level of interpretation required to classify each streambank and riparian characteristic. This assessment drew on observations made during preparation, implementation, and quality assurance, together with the quantitative agreement analyses (section 5). Particular consideration was given to characteristics requiring subjective interpretation (e.g. fence effectiveness, erosion severity, and riparian boundaries) compared with characteristics based primarily on direct observation or measurement (e.g. fence presence or vegetation type).

Ability to differentiate riparian condition

We evaluated the ability of each monitoring method to differentiate riparian condition by examining how consistently each method characterised variation in streambank and riparian characteristics among the study sites. The assessment considered whether each approach identified comparable patterns in fencing, riparian vegetation, stream shading, streambank erosion, and stock disturbance, and whether differences between methods were likely to reflect limitations in feature detectability, image resolution or interpretation. The quantitative agreement analyses were interpreted alongside qualitative observations made during implementation to assess the suitability of each monitoring approach for distinguishing differences in riparian condition.

Attention was given to characteristics expected to be sensitive to image resolution or observer interpretation, including fencing effectiveness, vegetation type, riparian vegetation width, stream shading, streambank erosion, and pugging. Differences between monitoring methods were interpreted in conjunction with the agreement analyses to determine whether they reflected genuine limitations in detectability or differences in how characteristics were observed.

4.4.3 Practicality of implementation

Resource requirements

We evaluated the relative resource requirements of each monitoring approach using information collected during project implementation. The assessment considered the complete monitoring workflow, including planning, data acquisition, fieldwork, interpretation, data processing, quality assurance, and reporting. For each method, we developed indicative estimates for:

- field and desktop assessment time per site
- travel and access requirements
- equipment and software requirements
- imagery acquisition costs
- specialist skills and training requirements
- data processing and quality assurance effort
- suitability for implementation at regional and national scales.

We considered both direct costs (e.g. staff time, travel, imagery acquisition, equipment, and software) and indirect costs (e.g. time spent obtaining landowner permissions, data management, and quality assurance). Scalability was evaluated by considering the practicality of extending each approach from individual sites to regional-scale monitoring programmes, including the feasibility of repeat surveys, dependence on specialist personnel, and availability of the required data sets.

Operational considerations

We evaluated operational considerations by examining the practical constraints associated with implementing each monitoring approach within regional council monitoring programmes. The assessment considered:

- site access requirements
- landowner permissions
- health and safety considerations
- staff and resource requirements
- travel and logistical requirements
- weather dependence
- privacy considerations
- constraints associated with imagery acquisition and survey timing.

For field-based surveys, emphasis was placed on the practical challenges associated with obtaining site access, undertaking surveys safely and efficiently, and maintaining consistent field coverage under a range of environmental conditions. For imagery-based methods, assessment focused on the availability, frequency, spatial coverage, and resolution of imagery data sets, together with constraints associated with remote interpretation and imagery acquisition schedules.

Technical requirements

We evaluated technical requirements by considering the expertise, software, data-processing workflows, and information management needed to implement each monitoring approach. Evaluation criteria included:

- technical expertise and training requirements
- equipment and software dependencies
- data processing and quality assurance requirements
- compatibility with standard GIS and data management systems
- suitability for spatial analysis and reporting
- potential for future automation and integration with national monitoring frameworks.

Consideration was given to each method's ability to produce consistent, spatially explicit data sets that could be readily stored, analysed, quality assured, and reported using standard GIS workflows. The assessment also considered reliance on specialist skills, proprietary software, and custom processing procedures, together with opportunities for future automation and integration with complementary spatial data sets.

5 Results and discussion

5.1 Data set overview

We assessed a total of 31 stream reaches using three survey approaches: field-based surveys, high-resolution aerial imagery, and standard-resolution aerial imagery. Each site consisted of an approximately 500 m stream reach and its associated riparian corridor, resulting in the assessment of approximately 15.5 km of stream length.

Our results compare the consistency of streambank and riparian characteristics derived from each survey method across these riparian characteristics: fencing and stock exclusion, riparian vegetation and stream shading, streambank erosion and stock pugging, and channel obstructions. Because each method provides different information and perspectives, comparisons focus on the level of agreement between methods rather than assuming a single universal reference standard.

We did not assume a single monitoring method represented a universal reference standard because the ability to assess individual streambank and riparian characteristics varies between methods. Although field surveys provide direct observations of site conditions for many streambank and riparian characteristics, aerial imagery offers advantages for assessing characteristics that depend on spatial context, continuity, or the extent and benefit of an aerial perspective. In addition, several characteristics were expected to differ legitimately between methods because they are inherently time-sensitive (e.g. stock presence, temporary fencing, or recent vegetation management), or because they are only observable from a particular viewpoint. Consequently, the primary focus was to evaluate each monitoring method according to its ability to characterise individual streambank and riparian characteristics.

Field surveys provided direct observations of site conditions and therefore served as the primary reference or best-estimate comparative benchmark for attributes requiring fine-scale assessment, such as fence type, vegetation type and streambank erosion. In contrast, aerial imagery provided a consistent overhead perspective that is well suited to assessing spatial characteristics such as riparian vegetation width and extent, and channel context. Consequently, some imagery-derived attributes may be equally representative – or in some cases more representative – than field observations. In response, our comparisons focused on the level of agreement between methods and the extent to which individual streambank and riparian characteristics could be reliably assessed using each approach.

5.1.1 General site characteristics

The 31 sites encompassed a range of farming systems, land uses, and stream types that are representative of pastoral and horticultural landscapes within the study region (Table 2). Drystock farming was the dominant farm type, accounting for 68% of sites classified during the field survey and 58% classified from aerial imagery, while horticultural enterprises represented 26% and 32% of sites, respectively. Land use adjacent to the stream reaches was similarly dominated by sheep & beef farming (68% field survey; 58% imagery), followed by orchards (19% and 23%, respectively). Stream permanence classifications were identical between methods, with 18 sites (58%) classified as permanently flowing and 13 sites (42%) classified as intermittent or non-permanent.

Agreement between methods for these broad site characteristics was high. The small differences in farm type and land-use classification reflected temporal differences between field surveys and image acquisition, together with limitations in what could be reliably distinguished from aerial imagery. In some cases, land use had genuinely changed between survey dates, with pasture being cultivated, cropped, or recently re-sown when the aerial imagery was captured. In other cases, imagery interpretation could not reliably distinguish specific land-use types, resulting in broader classifications (e.g. horticulture or cropping) where field surveys identified more specific uses such as vineyards, maize cropping, or lifestyle blocks.

Table 2. Summary of site characteristics derived from field surveys and high-resolution imagery interpretation. Values are presented as the number of sites (*n*) and the corresponding percentage of all sites (*n* = 31).

Attribute	Class	Field survey	High-resolution imagery
Farm type	Drystock	21 (68%)	18 (58%)
	Horticulture	8 (26%)	10 (32%)
	Cropping	1 (3%)	2 (7%)
	Lifestyle	1 (3%)	1 (3%)
Land use	Sheep & beef	21 (68%)	18 (58%)
	Orchard	6 (19%)	7 (23%)
	Horticulture	–	3 (10%)
	Vineyard	2 (7%)	–
	Cropping	–	2 (7%)
	Maize cropping	1 (3%)	–
	Built-up area	–	1 (3%)
	Other	1 (3%)	–
Permanent flow	Yes	18 (58%)	18 (58%)
	No	13 (42%)	13 (42%)

Note: Farm type and land use are for the land immediately adjacent to the waterway/riparian zone at the time of the survey and represents the dominant farm type associated with the riparian zone when there is a mixture of farms and land uses. A dash (–) indicates that no sites were classified in that category.

Point observations (only recorded for the field survey) indicated that the surveyed reaches were predominantly narrow, fine-sediment bed streams typical of lowland pastoral and horticultural catchments (Table 3). Banks were most commonly concave (42%) or linear (38%) in profile, with relatively steep bank slopes, most frequently 45° (28%) and 80° (24%). Channel widths were generally less than 5 m, with over one-third of observations between 1 and 2 m wide (36%) and a further 20% between 3 and 5 m wide. Streambeds were dominated by silt (79%), with gravel (11%), cobble (8%), and sand (2%) occurring less frequently. Livestock access was absent at most observation points (61%), while evidence of recent (23%) or current (16%) stock access was recorded at the remaining sites.

Collectively, the sites encompassed a broad range of riparian conditions (but not all), including unfenced and fully fenced reaches, narrow and wide riparian margins, grass-dominated and woody vegetation communities, reaches exhibiting active streambank erosion, and varying levels of stock access. Dairy farming was absent because of the predominance of drystock and horticultural land uses, the data set captured variability in streambank and riparian condition. This diversity provided a basis for evaluating the performance of the three monitoring approaches across the range of conditions commonly encountered in pastoral and horticultural catchments.

Table 3. Physical characteristics of field-survey sites based on point observations (*n* = 92)

Attribute	Dominant classes	% observations
Bank shape	Concave	42
	Linear	38
	Convex	12
	Terraced	9
Bank slope	30°	18
	45°	28
	60°	15
	80°	24
Channel width	≤1 m	14
	>1–2 m	36
	>2–3 m	10
	>3–5 m	20
	>5–10 m	12
	>10 m	9
Streambed type	Silt	79
	Sand	2
	Gravel	11
	Cobble	8
Livestock access	None	61
	Recent	23
	Current	16

5.2 Agreement between monitoring methods

We evaluated agreement between the field survey, high-resolution imagery, and standard-resolution imagery using site-level estimates derived for each monitoring reach ($n = 31$). For each site the proportion of bank length assigned to each attribute class was calculated independently for each monitoring method. Mean site-level values were used to summarise overall patterns, with uncertainty expressed as 95% confidence intervals derived from variation among sites. Agreement between imagery- and field-survey-derived estimates was assessed using bias, mean absolute error (MAE), root mean square error (RMSE), and Pearson correlation coefficients (r). Bias was calculated as imagery minus field survey, with positive values indicating overestimation and negative values indicating underestimation relative to the field survey. Paired t-tests were used to determine whether the mean bias differed significantly from zero, with Holm-adjusted P values used to account for multiple comparisons between imagery methods and the field survey.

5.2.1 Fencing and stock exclusion

The three monitoring approaches produced similar estimates of fencing extent across the 31 monitoring sites (Table 4; Figure 7). Mean fenced bank length was estimated at 54.8% (95% CI: 43.6–66.0%) from the field survey, compared with 51.2% (39.6–62.7%) from high-resolution imagery and 47.0% (35.9–58.2%) from standard-resolution imagery. Estimates of effective fencing followed a similar pattern (53.7%, 47.8%, and 46.7%, respectively). Mean site-level estimates were broadly comparable among methods, although fencing extent varied considerably among monitoring sites, ranging from 0 to 100% of bank length across all three methods (Figure 7). Fence type was also broadly consistent between methods, with wire fencing representing the dominant fence type (31.7–40.7% of bank length), followed by electric fencing (0.0–18.0%), while wood/other fence types collectively accounted for less than 7% of bank length (Table 4).

Agreement statistics indicated that high-resolution imagery closely reproduced field survey estimates of both fenced bank length (mean difference = −3.6 percentage points; MAE = 10.9 percentage points; RMSE = 17.6 percentage points; $r = 0.84$) and effective fencing (mean difference = −6.0 percentage points; MAE = 11.2 percentage points; RMSE = 17.5 percentage points; $r = 0.86$) (Table 5). Paired t-tests indicated that mean differences were not significantly different from zero for fenced bank length ($P = 0.259$) or effective fencing ($P = 0.111$), indicating no evidence of consistent over- or underestimation relative to the field survey.

Standard-resolution imagery also reproduced the overall pattern of fencing but exhibited larger mean differences, lower correlations, and greater uncertainty than high-resolution imagery. Mean differences of −7.8 percentage points for fenced bank ($P = 0.138$) and −7.0 percentage points for effective fencing ($P = 0.111$) were likewise not significantly different from zero, although MAE and RMSE were consistently higher and correlations weaker ($r = 0.72$–0.73). Scatterplots demonstrated that both imagery approaches successfully reproduced the broad gradient in fencing condition across monitoring sites (Figure 8), although agreement declined for sites with intermediate levels of fencing, where estimates were more variable. Overall, fencing was among the most reliably assessed attributes from aerial imagery, with high-resolution imagery providing the closest agreement with field survey observations.

Table 4. Mean site-level estimates (95% confidence intervals) of fencing characteristics derived from field survey, high-resolution imagery, and standard-resolution imagery (*n* = 31)

		Field survey		High-resolution imagery		Standard-resolution imagery	
Attribute	Class	Mean (%)	95% CI	Mean (%)	95% CI	Mean (%)	95% CI
Fence type	Wire	31.7	21.8–41.7	39.9	29.2–50.6	40.7	30.0–51.4
	Electric	18.0	8.4–27.6	7.0	0.8–13.2	0.0	0.0–0.0
	Wood/other	3.9	0.6–7.1	4.3	0.2–8.3	6.3	1.2–11.5
Fence presence	Fenced	54.8	43.6–66.0	51.2	39.6–62.7	47.0	35.9–58.2
	Unfenced	45.2	34.0–56.4	48.8	37.3–60.4	53.0	41.8–64.1
Fencing class	Effective	53.7	42.6–64.8	47.8	35.7–59.8	46.7	35.7–57.8
	Ineffective	1.1	0.2–2.0	1.9	–1.1–4.8	0.0	0.0–0.0
	Effectiveness uncertain	0.0	0.0–0.0	1.5	–0.7–3.8	0.3	–0.2–0.8

Note: Values represent mean site-level percentages with 95% confidence intervals.

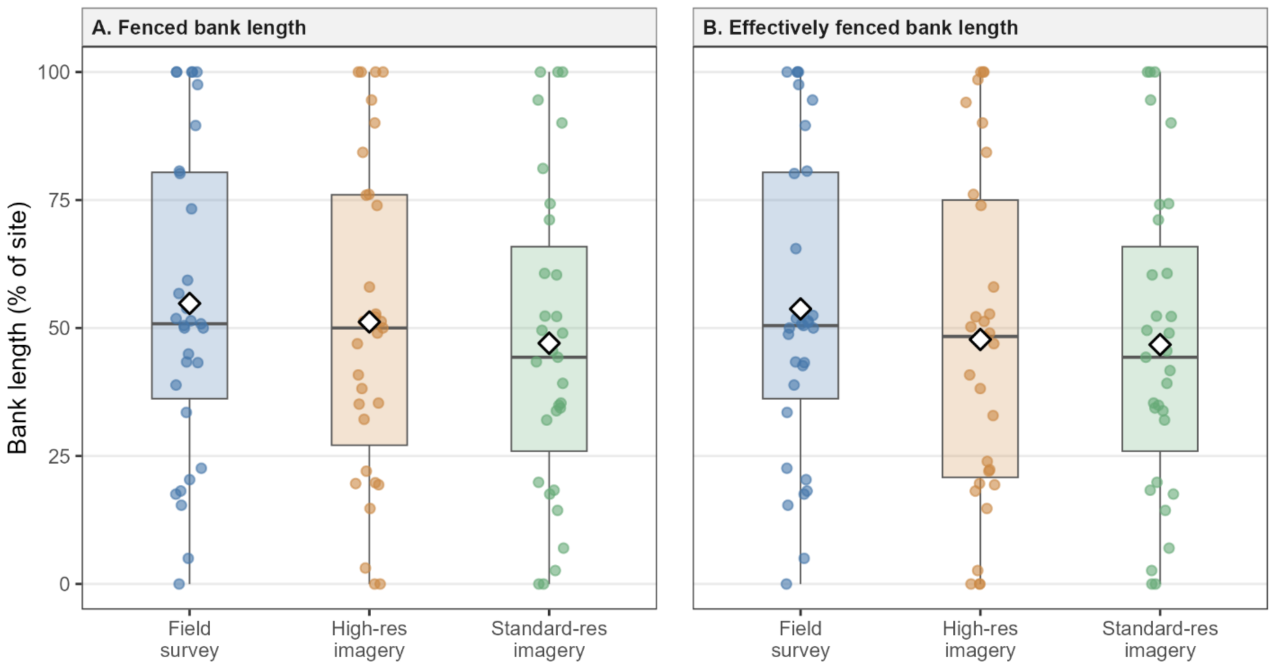

Figure 7. Distribution of site-level estimates for (A) fenced bank length and (B) effectively fenced bank length, derived from field survey, high-resolution imagery, and standard-resolution imagery (n = 31). Boxes represent the interquartile range (IQR), centre lines the median, and diamonds the mean. Whiskers extend to 1.5 × IQR, and points represent individual sites.

Table 5. Site-level agreement statistics for fencing attributes derived from high-resolution imagery and standard-resolution imagery relative to field survey observations (*n* = 31 sites)

Indicator	Method	Mean difference	Holm-adjusted *P*	MAE	RMSE	Pearson's *r*
Fenced bank length (%)	High-resolution imagery	–3.6	0.259	10.9	17.6	0.84
	Standard-resolution imagery	–7.8	0.138	13.1	23.8	0.72
Effective fencing (%)	High-resolution imagery	–6.0	0.111	11.2	17.5	0.86
	Standard-resolution imagery	–7.0	0.111	12.8	23.1	0.73

Notes: Mean difference was calculated as imagery minus field survey, with positive values indicating overestimation and negative values indicating underestimation relative to the field survey. Bias is presented with its 95% confidence interval. Paired *t*-tests with Holm-adjusted *P* values test the null hypothesis that the mean difference (imagery − field survey) equals zero. MAE = mean absolute error; RMSE = root mean square error.

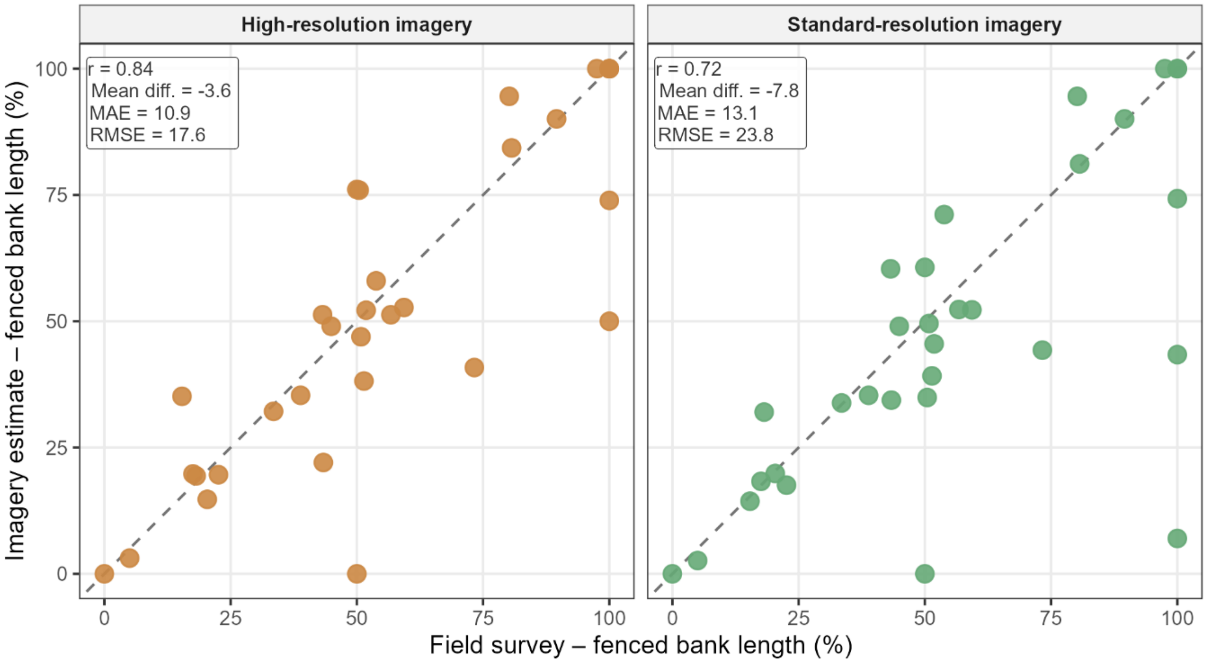

Figure 8. Site-level comparison of the proportion of fenced bank length (%) estimated from the field survey, high-resolution imagery, and standard-resolution imagery. The dashed line indicates perfect agreement (1:1), and panel annotations summarise Pearson's correlation coefficient (r), bias, mean absolute error (MAE), and root mean square error (RMSE) relative to the field survey.

5.2.2 Riparian vegetation and stream shading

Estimates of riparian vegetation were highly consistent among the three monitoring methods, particularly for the dominant vegetation classes, total woody vegetation extent (which combines woody mixed, woody native, woody evergreen, woody willow, and woody deciduous classes), and overall stream shading (Table 6; Figures 9–12). Grass and weeds were consistently the dominant vegetation type, accounting for approximately two-thirds of bank length under all three approaches (66.1–67.2%). Likewise, total woody vegetation extent was almost identical among methods, with mean site-level estimates ranging from 32.4% to 32.7%. The substantial overlap in confidence intervals indicated close agreement in overall vegetation cover.

Greater differences occurred in the classification of individual woody vegetation types (Figure 9). Standard-resolution imagery classified a larger proportion of woody vegetation as mixed woody vegetation (25.5%) than either high-resolution imagery (18.2%) or the field survey (10.4%), whereas the field survey recorded higher proportions of woody native, willow, and deciduous vegetation. These differences reflect the greater ability of field surveys to distinguish vegetation composition, while imagery (especially standard-resolution imagery) more frequently grouped mixed or indistinct woody communities into broader classes.

Vegetation-width estimates showed greater differences between methods (Figure 10). Both imagery data sets estimated larger proportions of bank length within the narrowest (≤1 m) and widest (>10 m) vegetation-width classes, whereas the field survey recorded higher proportions within the intermediate width classes (>1–5 m).

Patterns of stream shading were broadly comparable among methods, although differences occurred in the distinction between complete and incomplete shading (Figure 11). The field survey recorded a greater proportion of incomplete shading (30.3%) than either high-resolution imagery (15.5%) or standard-resolution imagery (17.5%), whereas complete shading was identified more frequently from imagery (11.7–11.9%) than during the field survey (4.7%). However, when complete and incomplete shading were combined, estimates of total shading were much more consistent, averaging 35.0% for the field survey, 27.3% for high-resolution imagery, and 29.4% for standard-resolution imagery (Table 6). These results indicate that imagery was less consistent in distinguishing shading intensity but produced broadly comparable estimates of the overall extent of stream shading.

Table 6. Mean site-level estimates (95% confidence intervals) of riparian vegetation attributes derived from field survey, high-resolution imagery, and standard-resolution imagery (*n* = 31)

		Field survey		High-resolution imagery		Standard-resolution imagery	
Attribute	**Class**	**Mean (%)**	**95% CI**	**Mean (%)**	**95% CI**	**Mean (%)**	**95% CI**
Vegetation type	Grass & weeds	66.1	56.4–75.8	66.6	57.4–75.9	67.2	57.9–76.5
	Woody mixed	10.4	3.3–17.4	18.2	8.4–28.0	25.5	15.3–35.7
	Woody native	6.9	0.7–13.0	3.3	0.0–8.7	0.0	0.0–0.0
	Woody evergreen	6.2	2.3–10.1	5.7	1.3–10.2	5.2	0.2–10.1
	Woody willow	5.7	1.9–9.6	3.2	0.4–6.0	0.5	0.0–1.3
	Woody deciduous	3.5	0.7–6.3	2.0	0.2–3.8	1.3	0.0–2.6
	Flax/sedge/rush	1.2	0.2–2.3	0.9	0.0–1.8	0.4	0.0–1.0
Vegetation width	≤1 m	26.0	15.4–36.6	29.5	17.5–41.5	28.7	16.5–41.0
	>1–2 m	21.1	11.0–31.3	15.4	5.2–25.6	9.8	2.6–17.0
	>2–3 m	14.9	9.1–20.7	8.3	2.8–13.8	9.5	1.8–17.2
	>3–5 m	14.5	7.9–21.1	12.8	5.9–19.7	13.5	6.7–20.4
	>5–10 m	8.2	4.3–12.2	12.2	5.3–19.1	15.1	7.0–23.3
	>10 m	15.2	6.4–24.0	21.8	11.5–32.0	23.2	12.3–34.2
Stream shade	Complete shading	4.7	0.0–10.1	11.7	4.3–19.2	11.9	4.1–19.6
	Incomplete shading	30.3	20.2–40.4	15.5	10.1–20.9	17.5	11.7–23.4
	Total shading	35.0	23.8–46.3	27.3	18.7–35.8	29.4	20.2–38.6
	No shading	65.0	53.7–76.2	72.7	64.2–81.3	70.6	61.4–79.8
Woody vegetation	Non-woody vegetation	67.3	57.4–77.3	67.6	58.1–77.0	67.6	58.2–77.0
	Woody vegetation	32.7	22.7–42.6	32.4	23.0–41.9	32.4	23.0–41.8

Notes: Values represent mean site-level percentages with 95% confidence intervals. Lower confidence limits were truncated to 0.0 where the normal approximation produced negative values.

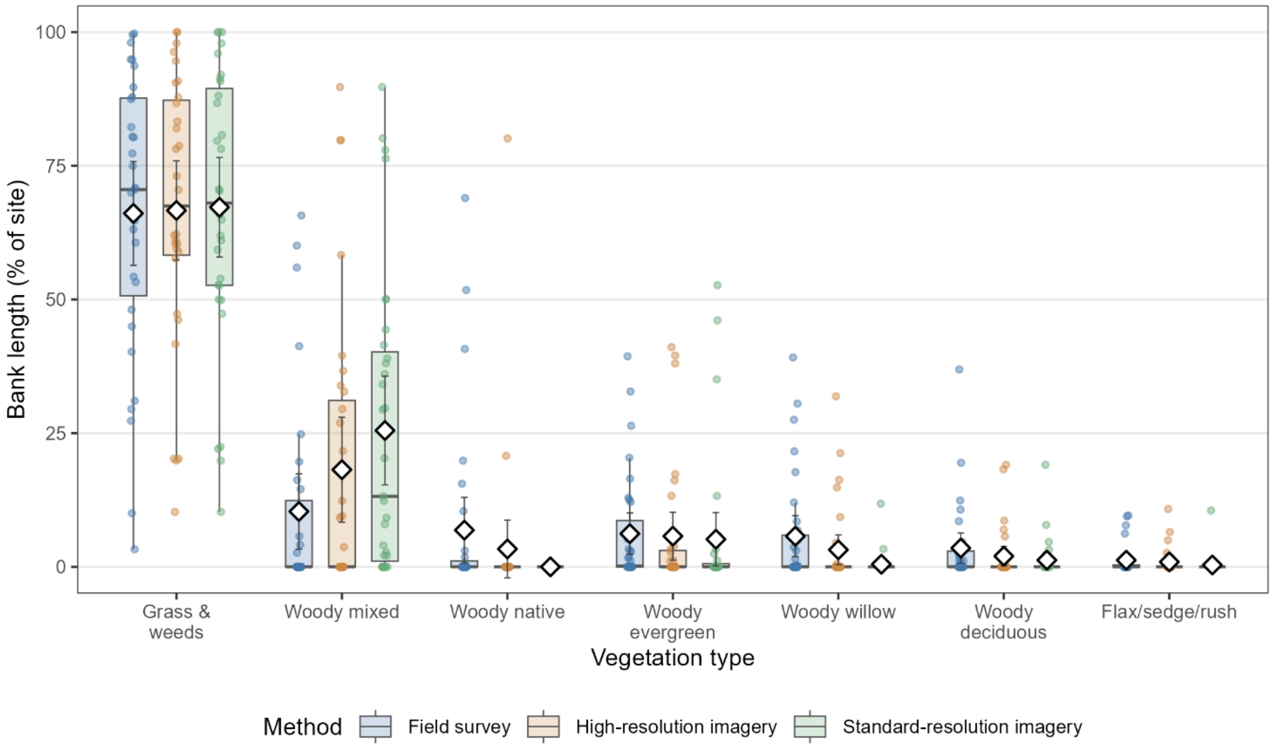

Figure 9. Mean site-level estimates of riparian vegetation type classes derived from field survey, high-resolution imagery, and standard-resolution imagery (n = 31). Boxes represent the interquartile range (IQR), centre lines the median, and diamonds the mean. Whiskers extend to 1.5 × IQR, and points represent individual sites.

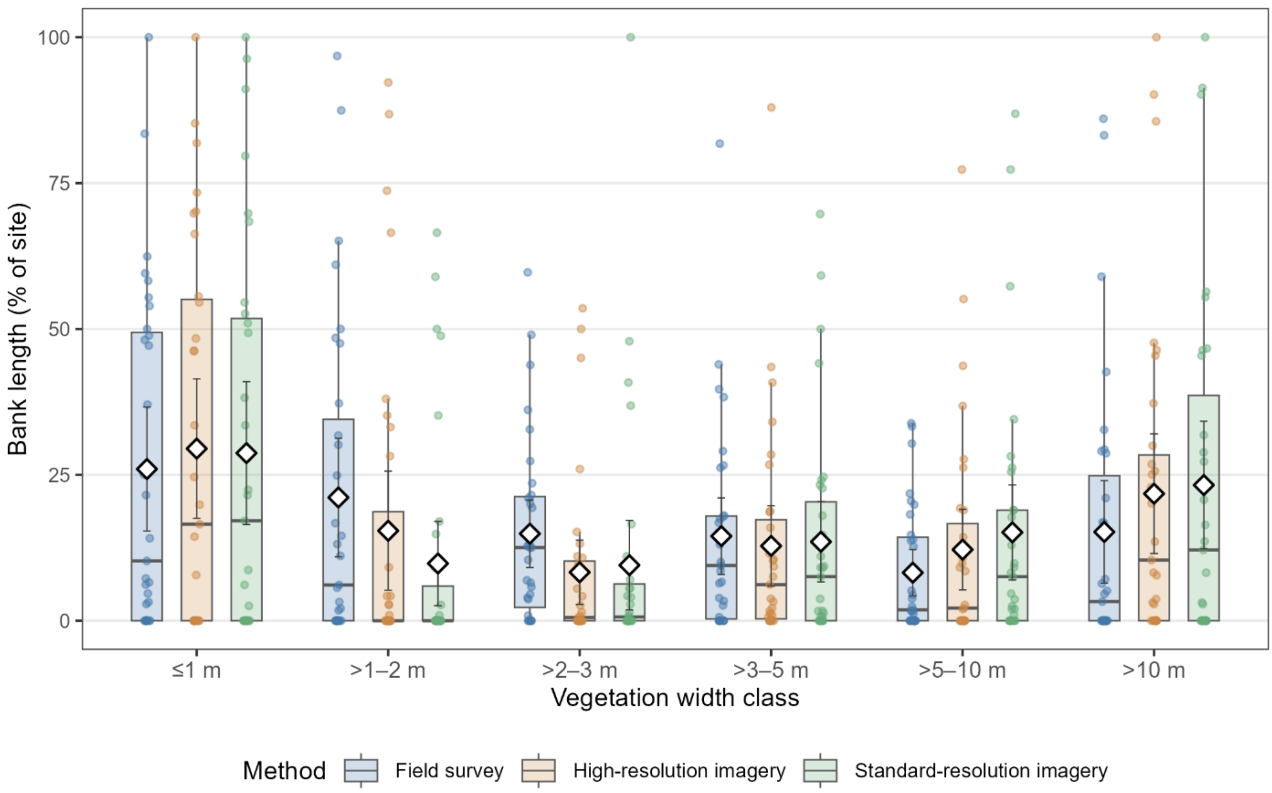

Figure 10. Mean site-level estimates of riparian vegetation width classes derived from field survey, high-resolution imagery, and standard-resolution imagery (*n* = 31). Boxes represent the interquartile range (IQR), centre lines the median, and diamonds the mean. Whiskers extend to 1.5 × IQR, and points represent individual sites.

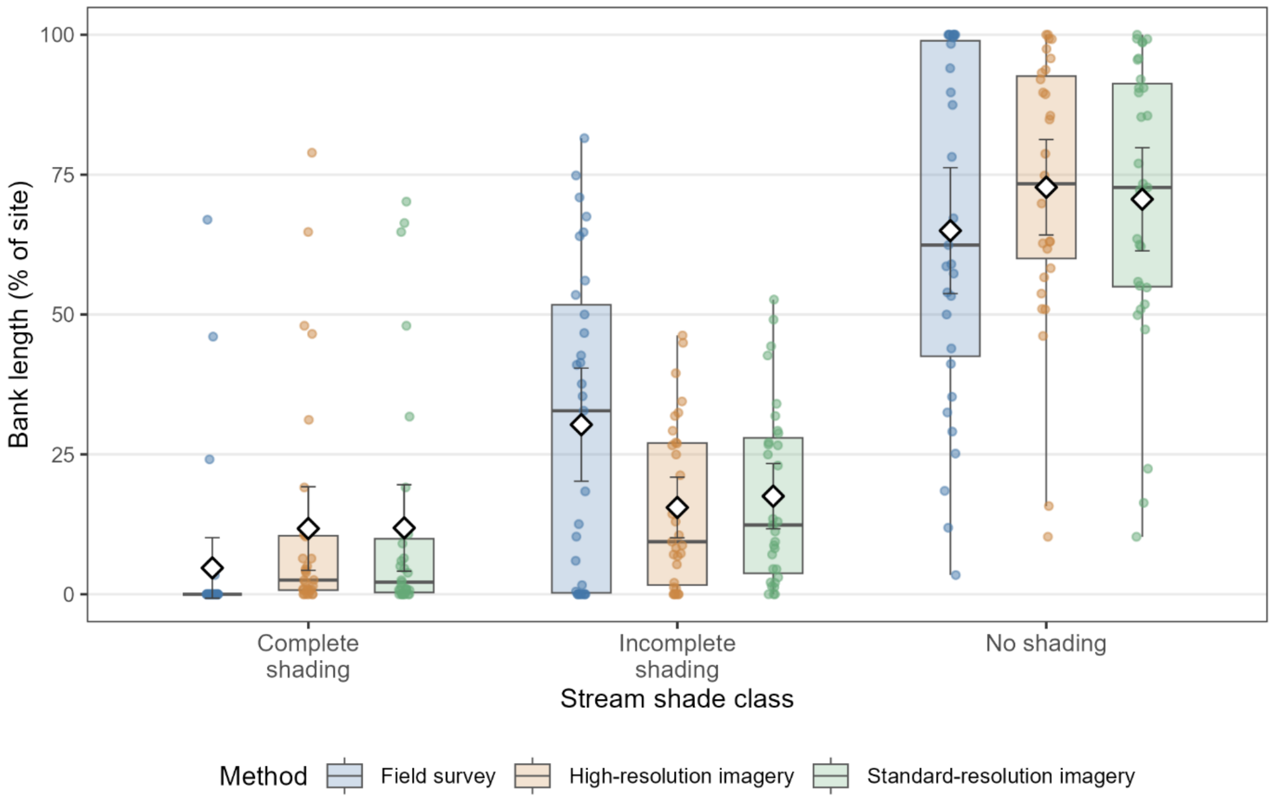

Figure 11. Mean site-level estimates of stream shading classes derived from field survey, high-resolution imagery, and standard-resolution imagery (n = 31). Boxes represent the interquartile range (IQR), centre lines the median, and diamonds the mean. Whiskers extend to 1.5 × IQR, and points represent individual sites.

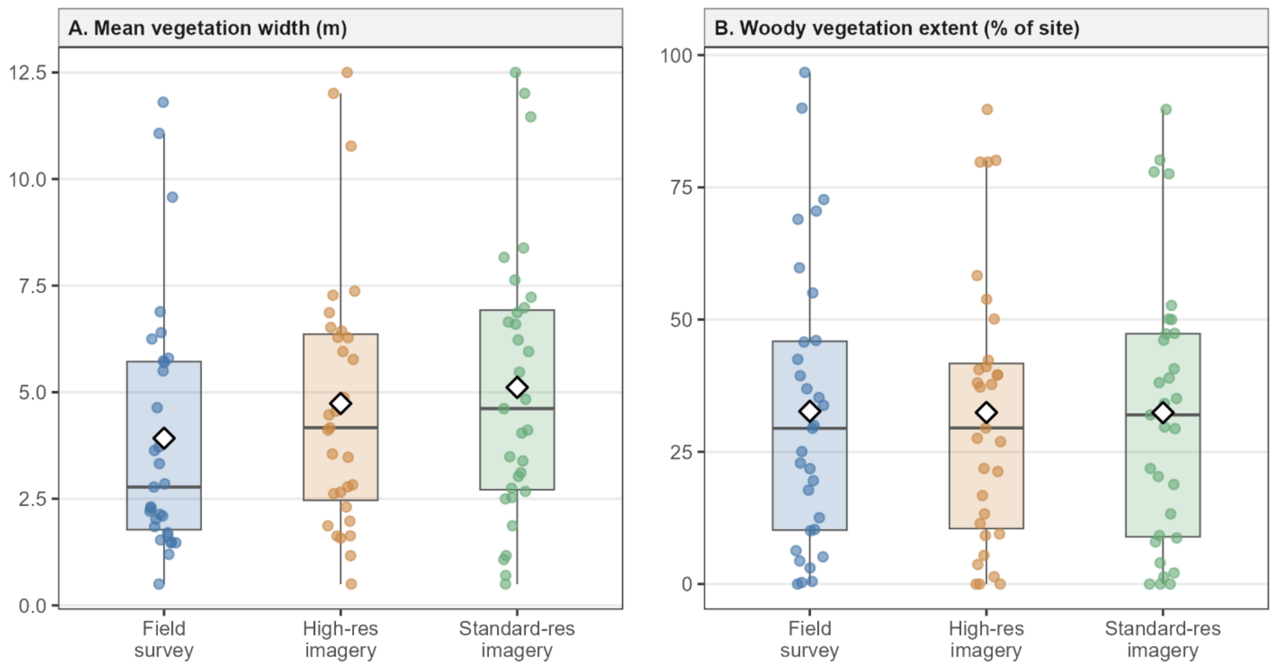

Figure 12. Distribution of site-level estimates for (A) mean riparian vegetation width (m) and (B) woody vegetation extent (%) derived from field survey, high-resolution imagery, and standard-resolution imagery (n = 31). Boxes represent the interquartile range (IQR), centre lines the median, and diamonds the mean. Whiskers extend to 1.5 × IQR, and points represent individual monitoring sites.

Agreement statistics confirmed that woody vegetation extent was the strongest-performing vegetation indicator (Table 7). High-resolution imagery closely matched field survey estimates (mean difference = −0.2 percentage points; MAE = 5.9 percentage points; RMSE = 8.5 percentage points; *r* = 0.95), while standard-resolution imagery also performed well despite larger errors (mean difference = −0.2 percentage points; MAE = 10.5 percentage points; RMSE = 17.0 percentage points; *r* = 0.79). Paired *t*-tests indicated that mean differences were not statistically significantly different from zero for either imagery method (*P* = 1.000), providing no evidence of systematic over- or underestimation of total woody vegetation extent relative to field survey estimates.

Mean riparian vegetation width also showed good agreement, particularly for high-resolution imagery (mean difference = +0.8 m; MAE = 1.3 m; RMSE = 1.9 m; *r* = 0.84). Standard-resolution imagery produced slightly larger mean differences and errors (mean difference = +1.2 m; MAE = 1.9 m; RMSE = 2.4 m; *r* = 0.75). However, paired *t*-tests indicated that both imagery methods significantly overestimated mean riparian vegetation width relative to the field survey (*P* = 0.012 and 0.009, respectively).

Table 7. Site-level agreement statistics for riparian vegetation and stream shading indicators derived from high-resolution imagery and standard-resolution imagery relative to field survey observations (*n* = 31)

Indicator	Method	Mean difference	Holm-adjusted *P*	MAE	RMSE	Pearson's *r*
Woody vegetation extent (%)	High-resolution imagery	–0.2	1.000	5.9	8.5	0.95
	Standard-resolution imagery	–0.2	1.000	10.5	17.0	0.79
Mean riparian vegetation width (m)	High-resolution imagery	0.8	0.012	1.3	1.9	0.84
	Standard-resolution imagery	1.2	0.009	1.9	2.4	0.75
Complete stream shading (%)	High-resolution imagery	7.0	0.013	7.2	14.9	0.76
	Standard-resolution imagery	7.2	0.013	7.3	16.3	0.71
Overall stream shading (%)	High-resolution imagery	–7.8	0.023	11.2	17.6	0.86
	Standard-resolution imagery	–5.6	0.057	10.5	16.5	0.86

Notes: Mean difference was calculated as imagery minus field survey, with positive values indicating overestimation and negative values indicating underestimation relative to the field survey. Bias is presented with its 95% confidence interval. Paired *t*-tests with Holm-adjusted *P* values test the null hypothesis that the mean difference (imagery − field survey) equals zero. MAE = mean absolute error; RMSE = root mean square error.

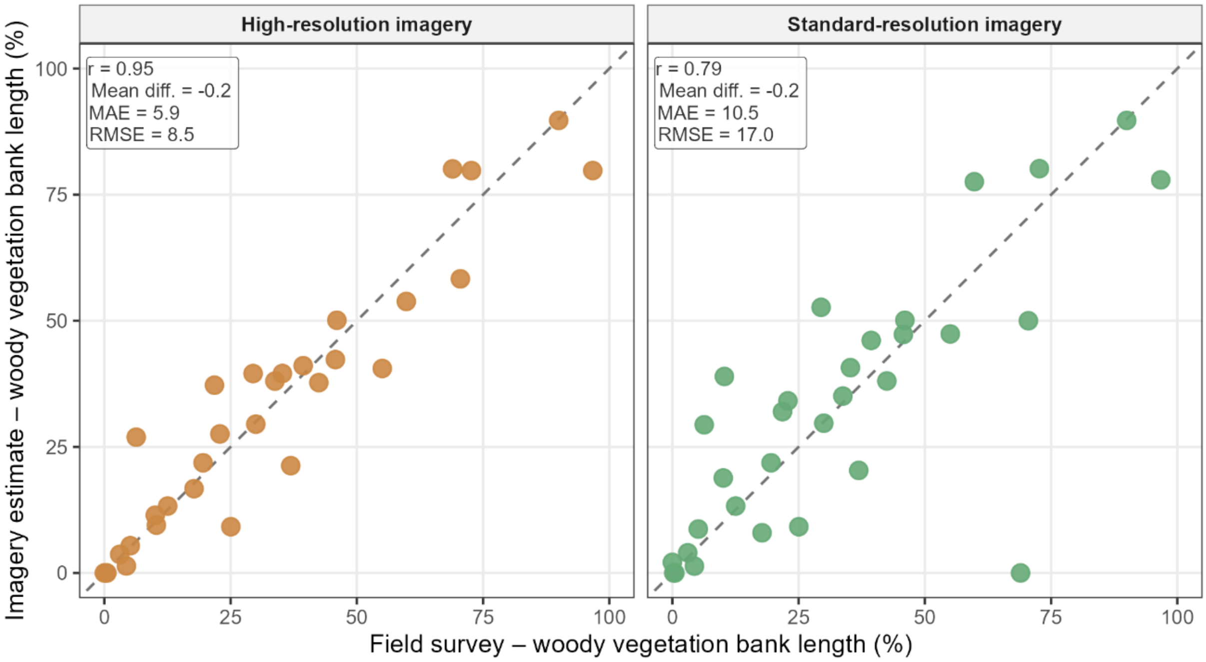

Figure 13. Site-level comparison of woody vegetation bank length (%) estimated from high-resolution imagery (left) and standard-resolution imagery (right) relative to field survey estimates. The dashed line indicates perfect agreement (1:1), and panel annotations summarise Pearson's correlation coefficient (r), bias, mean absolute error (MAE), and root mean square error (RMSE) relative to the field survey.

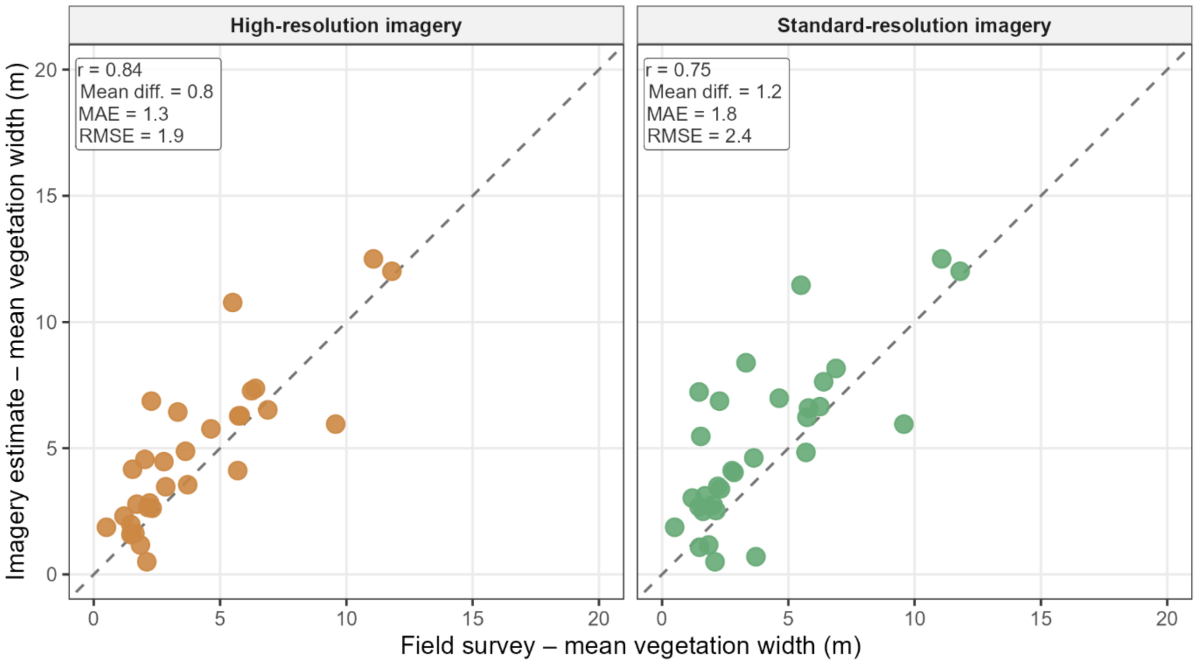

Figure 14. Site-level comparison of mean riparian vegetation width (m) estimated from high-resolution imagery (left) and standard-resolution imagery (right) relative to field survey estimates. The dashed line indicates perfect agreement (1:1), and panel annotations summarise Pearson's correlation coefficient (r), bias, mean absolute error (MAE), and root mean square error (RMSE) relative to the field survey.

Agreement for stream shading was more variable than for woody vegetation extent or riparian vegetation width (Table 7). Agreement was lowest for complete shading, with both imagery methods substantially overestimating the proportion of completely shaded bank (mean differences = +7.0 and +7.2 percentage points, respectively), indicating difficulty distinguishing complete from partial canopy cover using aerial imagery. When complete and incomplete shading were combined into total shaded bank length, agreement improved substantially for both imagery methods. High-resolution imagery underestimated total shading by 7.8 percentage points (MAE = 11.2 percentage points; RMSE = 17.6 percentage points; r = 0.86), while standard-resolution imagery underestimated shading by 5.6 percentage points (MAE = 10.5 percentage points; RMSE = 16.5 percentage points; r = 0.86). The underestimate was statistically significant only for high-resolution imagery (P = 0.023).

Scatterplots demonstrated strong agreement between field survey- and imagery-derived estimates for woody vegetation extent, mean riparian vegetation width, and total shading (Figure 13Figures 13–15), while the alluvial diagrams show that disagreement in vegetation and stream-shading classes generally occurred between adjacent categories rather than completely different classes.

Overall, aerial imagery closely reproduced broad patterns in riparian vegetation and stream shading, particularly for woody vegetation extent, which showed the strongest agreement with field observations. High-resolution imagery consistently produced lower errors and stronger correlations than standard-resolution imagery. Although imagery-based assessments returned wider mean vegetation widths and had difficulty distinguishing complete from partial stream shading, they reproduced overall woody vegetation extent and total shading with good agreement. These results indicate that imagery was more reliable for quantifying overall vegetation structure than for discriminating finer-scale vegetation type or shading intensity.

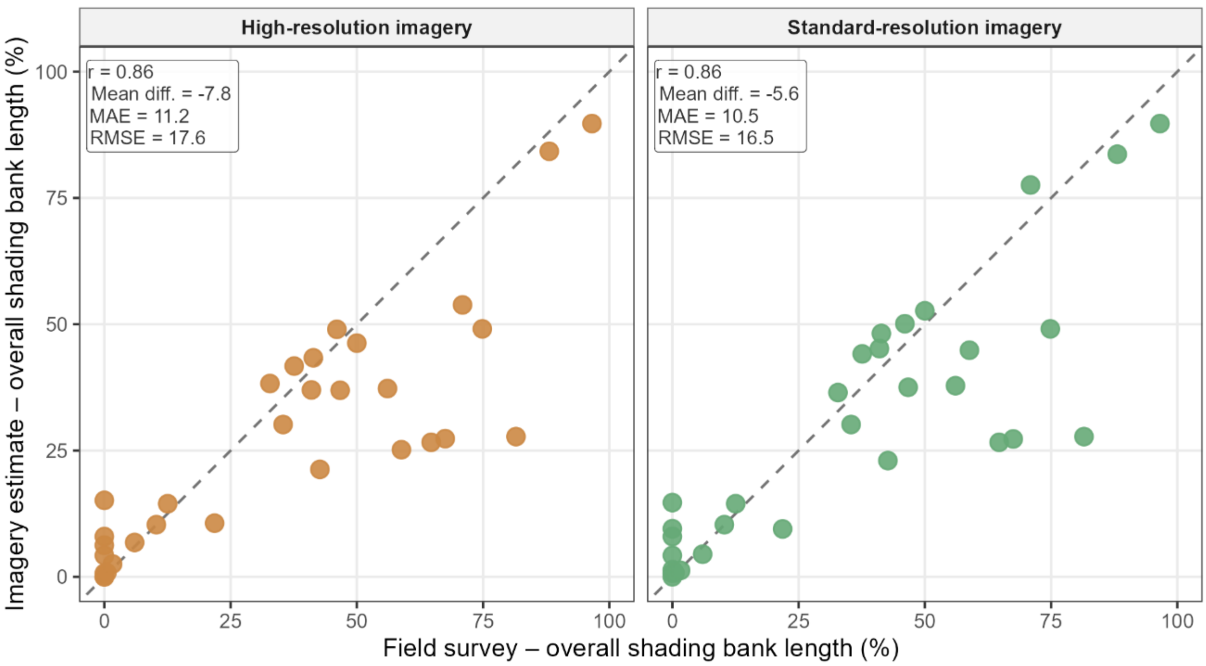

Figure 15. Site-level comparison of the proportion of bank length providing stream shading (%) estimated from high-resolution imagery (left) and standard-resolution imagery (right) relative to field survey estimates. The dashed line indicates perfect agreement (1:1), and panel annotations summarise Pearson's correlation coefficient (r), bias, mean absolute error (MAE), and root mean square error (RMSE) relative to the field survey.

5.2.3 Streambank erosion and stock pugging

Agreement for streambank erosion and stock pugging was lower than for fencing, riparian vegetation, and stream shading (Tables 8 and 9; Figures 16 and 17). The field survey estimated erosion or disturbance along a mean of 24.3% of bank length across monitoring sites, compared with 12.8% from high-resolution imagery and 9.5% from standard-resolution imagery (Figure 16). Both imagery methods therefore identified substantially less erosion or disturbance than was recorded during field surveys.

Pugging showed a similar but less consistent pattern (Figure 17). The field survey recorded visible pugging along 20.6% of bank length, comprising 15.3% with pugging affecting ≤50% of the bank and 5.3% affecting >50%. High-resolution imagery produced a similar estimate (18.4%), whereas standard-resolution imagery identified substantially less pugging (4.8%), largely because sites with low levels of pugging were frequently classified as having no pugging or were unobservable.

Agreement statistics confirmed that erosion or disturbance was the least reliably reproduced attribute by either imagery method (Table 9). High-resolution imagery underestimated erosion or disturbance by a mean of 11.5 percentage points (MAE = 18.0 percentage points; RMSE = 23.2 percentage points; $r = 0.46$), while standard-resolution imagery underestimated erosion by 14.8 percentage points (MAE = 17.4 percentage points; RMSE = 23.3 percentage points; $r = 0.51$). Paired *t*-tests indicate that both imagery methods significantly underestimated erosion or disturbance relative to the field survey ($P = 0.004$ and $P < 0.001$, respectively).

Table 8. Mean site-level estimates (95% confidence intervals) of streambank erosion and stock-disturbance attributes derived from field survey, high-resolution imagery, and standard-resolution imagery (*n* = 31)

		Field survey		High-resolution imagery		Standard-resolution imagery	
Attribute	**Class**	**Mean (%)**	**95% CI**	**Mean (%)**	**95% CI**	**Mean (%)**	**95% CI**
Erosion occurrence	Erosion/disturbance observed	24.3	16.7–31.8	12.8	6.0–19.5	9.5	4.2–14.7
	No erosion observed	73.1	65.3–80.9	69.0	58.2–79.8	66.1	55.2–77.0
	Unobserved	2.6	0.0–6.4	18.2	8.9–27.5	24.5	13.1–35.9
Pugging	No pugging	66.6	53.8–79.4	60.4	44.8–76.0	64.0	47.6–80.5
	Pugging ≤50%	15.3	5.0–25.5	15.9	5.7–26.0	3.5	0.0–7.3
	Pugging >50%	5.3	1.1–9.4	2.5	0.0–5.8	1.3	0.0–3.0
	Unobserved	12.9	2.3–23.5	21.3	8.9–33.7	31.2	16.1–46.2

Notes: Values represent mean site-level percentages with 95% confidence intervals. Lower confidence limits have been truncated to 0.0 where the normal approximation produced negative values.

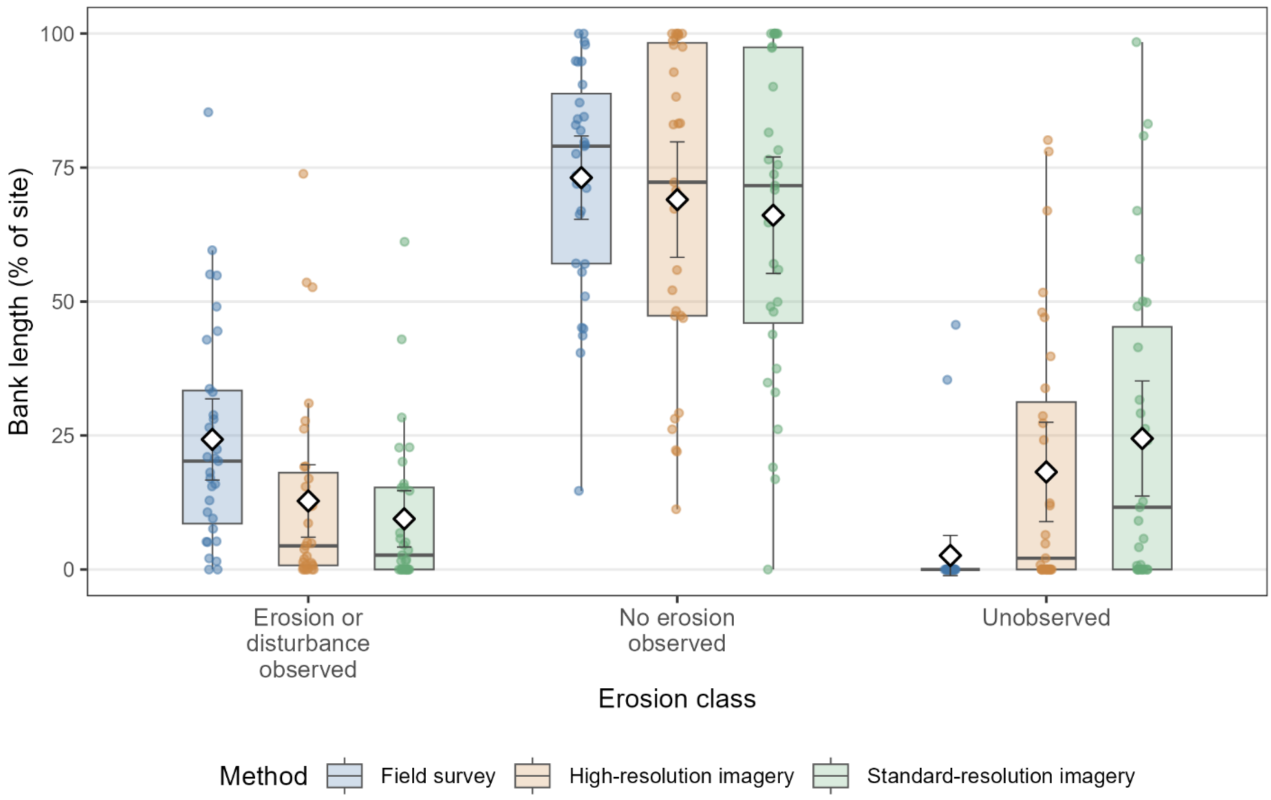

Figure 16. Mean site-level estimates of erosion or disturbance occurrence derived from field survey, high-resolution imagery, and standard-resolution imagery (n = 31). Boxes represent the interquartile range (IQR), centre lines the median, and diamonds the mean. Whiskers extend to 1.5 × IQR, and points represent individual sites.

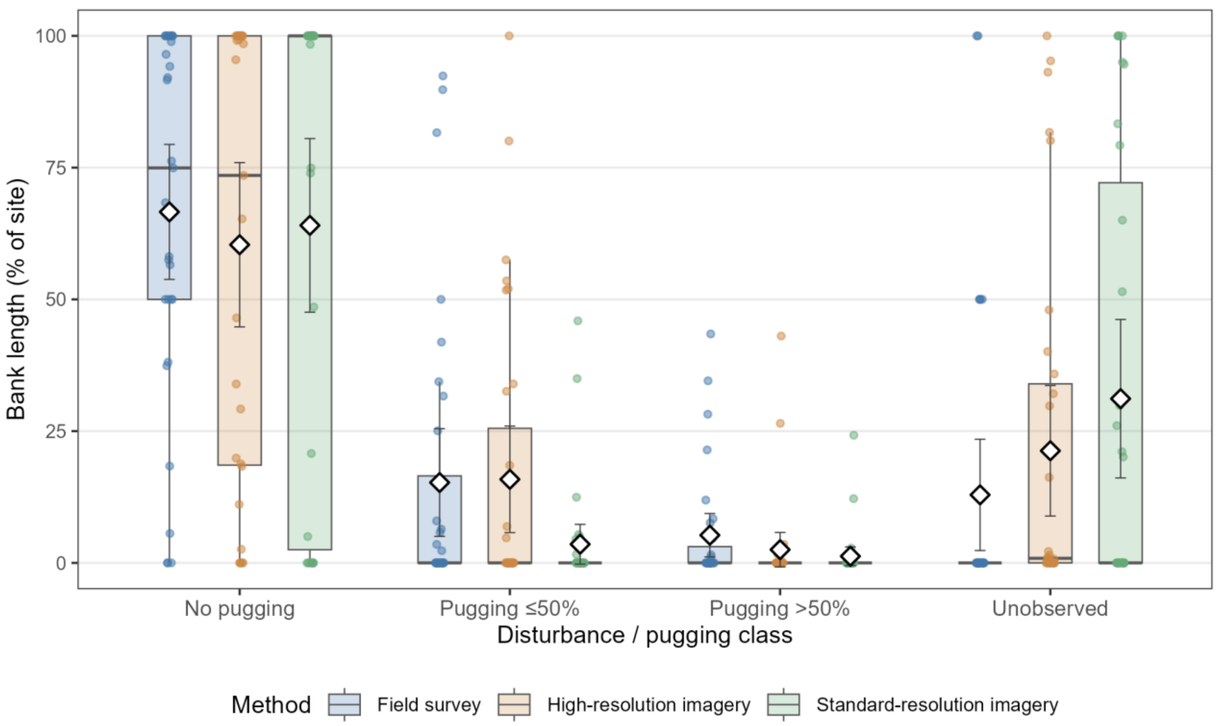

Figure 17. Mean site-level estimates of pugging severity classes derived from field survey, high-resolution imagery, and standard-resolution imagery (n = 31 sites). Boxes represent the interquartile range (IQR), centre lines the median, diamonds the mean, whiskers extend to 1.5 × IQR, and points represent individual sites.

Agreement for pugging was stronger than for erosion but differed substantially between imagery methods. High-resolution imagery underestimated pugging by a mean of 2.1 percentage points, although the mean difference was not statistically significant (MAE = 11.5 percentage points; RMSE = 21.3 percentage points; $r = 0.74$; $P = 0.585$). In contrast, standard-resolution imagery underestimated pugging by 15.7 percentage points and produced substantially larger errors and weaker agreement with the field survey (MAE = 18.7 percentage points; RMSE = 33.6 percentage points; $r = 0.26$). This underestimation was statistically significant ($P = 0.014$).

Scatterplots demonstrated that both imagery methods generally identified sites where erosion or pugging was present but underestimated the proportion of bank length affected, particularly at sites with greater disturbance (Figures 18 and 19). Overall, streambank erosion and pugging were the least consistently assessed attributes using aerial imagery. Both indicators were generally underestimated, particularly by standard-resolution imagery, reflecting the difficulty of detecting subtle or localised ground-surface disturbance from an overhead perspective. High-resolution imagery improved agreement but still failed to capture the full extent of disturbance observed during field surveys.

Table 9. Site-level agreement statistics for streambank erosion and stock-disturbance indicators derived from high-resolution imagery and standard-resolution imagery relative to field survey observations (*n* = 31)

Indicator	Method	Mean difference	Holm-adjusted *P*	MAE	RMSE	Correlation (*r*)
Erosion or disturbance observed (%)	High-resolution imagery	–11.5	0.004	18.0	23.2	0.46
	Standard-resolution imagery	–14.8	<0.001	17.4	23.3	0.51
Pugging observed (%)	High-resolution imagery	–2.1	0.585	11.5	21.3	0.74
	Standard-resolution imagery	–15.7	0.014	18.7	33.6	0.26

Notes: Mean difference was calculated as imagery minus field survey, with positive values indicating overestimation and negative values indicating underestimation relative to the field survey. Bias is presented with its 95% confidence interval. Paired *t*-tests with Holm-adjusted *P* values test the null hypothesis that the mean difference (imagery − field survey) equals zero. MAE = mean absolute error; RMSE = root mean square error.

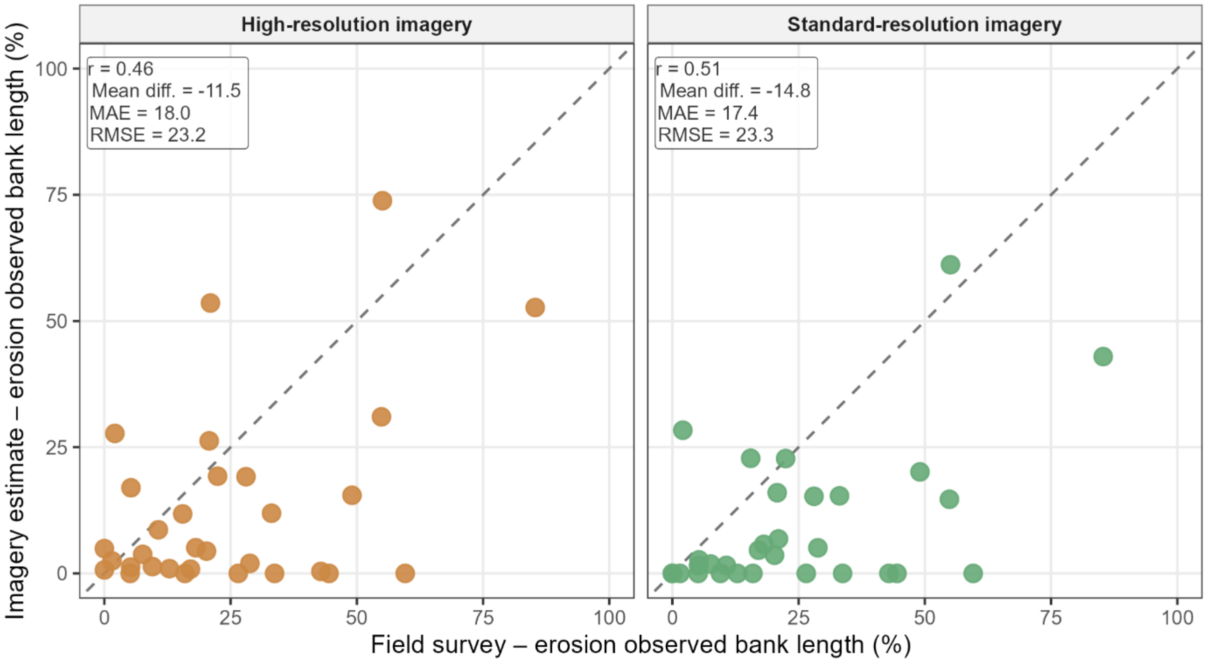

Figure 18. Site-level comparison of erosion-affected bank length (%) estimated from high-resolution imagery (left) and standard-resolution imagery (right) relative to field survey estimates. The dashed line indicates perfect agreement (1:1), and panel annotations summarise Pearson's correlation coefficient (*r*), bias, mean absolute error (MAE), and root mean square error (RMSE) relative to the field survey.

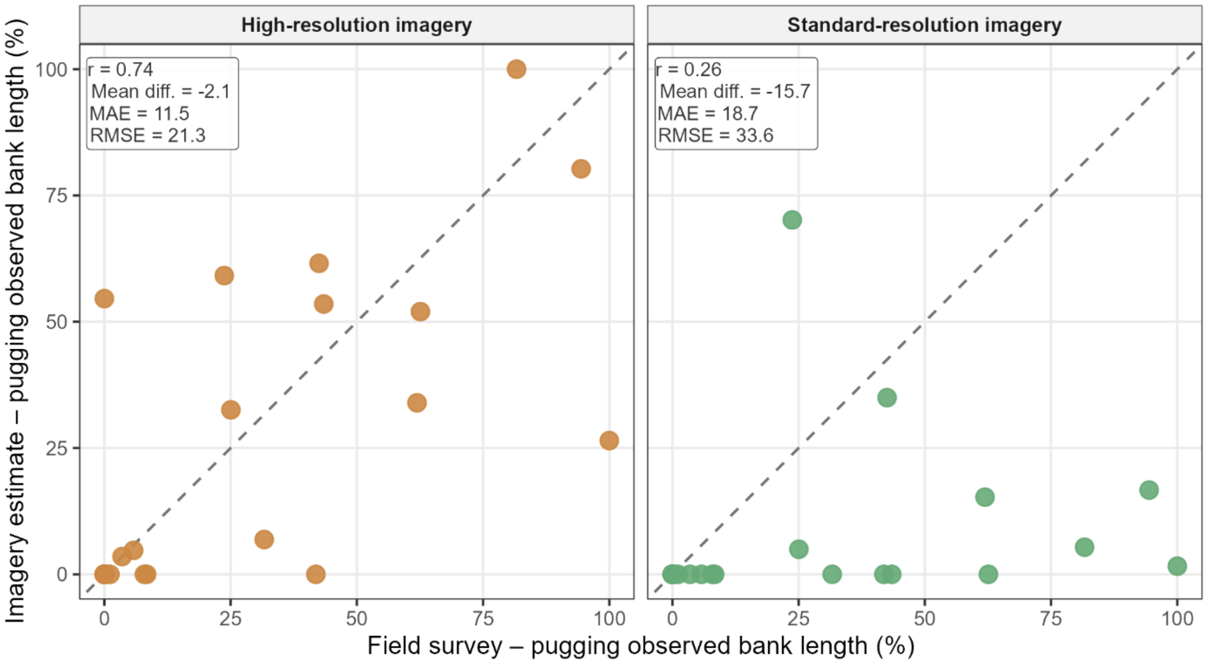

Figure 19. Site-level comparison of pugging-affected bank length (%) estimated from high-resolution imagery (left) and standard-resolution imagery (right) relative to field survey estimates. The dashed line indicates perfect agreement (1:1), and panel annotations summarise Pearson's correlation coefficient (*r*), bias, mean absolute error (MAE), and root mean square error (RMSE) relative to the field survey.

5.2.4 Channel obstructions

Detecting the presence and nature of channel obstructions differed more substantially between the field survey and imagery-based assessments than most other attributes (Tables 10–12; Figure 20). The field survey identified a greater number of channel obstructions than either imagery method, recording a total of 130 channel obstructions across the 31 monitoring sites, compared with 63 from high-resolution imagery and 54 from standard-resolution imagery (Table 10). At the site level, the field survey identified a mean of 4.2 channel obstructions per site (95% CI: 2.8–5.6), compared with 2.0 (1.3–2.8) from high-resolution imagery and 1.7 (1.1–2.4) from standard-resolution imagery (Table 11; Figure 20). Both imagery methods therefore consistently identified fewer channel obstructions than the field survey.

Agreement statistics indicated only moderate correspondence between methods (Table 12). High-resolution imagery underestimated channel obstruction counts by a mean of 2.2 channel obstructions per site (MAE = 2.5; RMSE = 4.0; r = 0.47), while standard-resolution imagery underestimated counts by 2.5 channel obstructions per site (MAE = 2.6; RMSE = 4.0; r = 0.55). Paired t-tests indicate that the mean differences for both imagery methods were significantly different from zero ($P = 0.001$ and $P < 0.001$, respectively), demonstrating that both imagery approaches underestimated the number of visible channel obstructions relative to the field survey.

Scatterplots showed that agreement was strongest where few or no channel obstructions were present and declined as channel obstruction counts increased (Figure 21). Sites with numerous vegetation, terrain, or infrastructure-related channel obstructions were consistently underestimated by both imagery methods, reflecting the inability of overhead imagery to fully capture three-dimensional visibility constraints encountered during field surveys.

Overall, channel obstruction detection was among the most method-dependent of the attributes assessed. Unlike most other variables, differences largely reflected the contrasting perspectives of ground-based and aerial surveys rather than differences in attribute interpretation. Vegetation, terrain, and channel morphology influenced stream visibility differently for each survey approach, resulting in lower channel obstruction counts from aerial imagery, particularly where riparian vegetation was dense or channel morphology was complex.

Table 10. Total number (*n*) of channel obstruction types identified from field survey, high-resolution imagery, and standard-resolution imagery across all monitoring sites

Attribute	Class	Field survey (*n*)	High-resolution imagery (*n*)	Standard-resolution imagery (*n*)
Channel obstructions	Side entry	32	4	2
	Culvert	32	20	20
	Other live vegetation/ Willow	34	18	13
	Non-living debris	13	8	8
	Bridge >10 m	9	8	7
	Dam/weir	6	4	3
	Streambed/constructed ford	4	1	1
	Total	**130**	**63**	**54**

Table 11. Mean site-level estimates (95% confidence intervals) of channel obstruction counts derived from field survey, high-resolution imagery, and standard-resolution imagery (*n* = 31)

	Field survey		High-resolution imagery		Standard-resolution imagery	
Indicator	**Mean (%)**	**95% CI**	**Mean (%)**	**95% CI**	**Mean (%)**	**95% CI**
Channel obstruction count (per site)	4.2	2.8–5.6	2.0	1.3–2.8	1.7	1.1–2.4

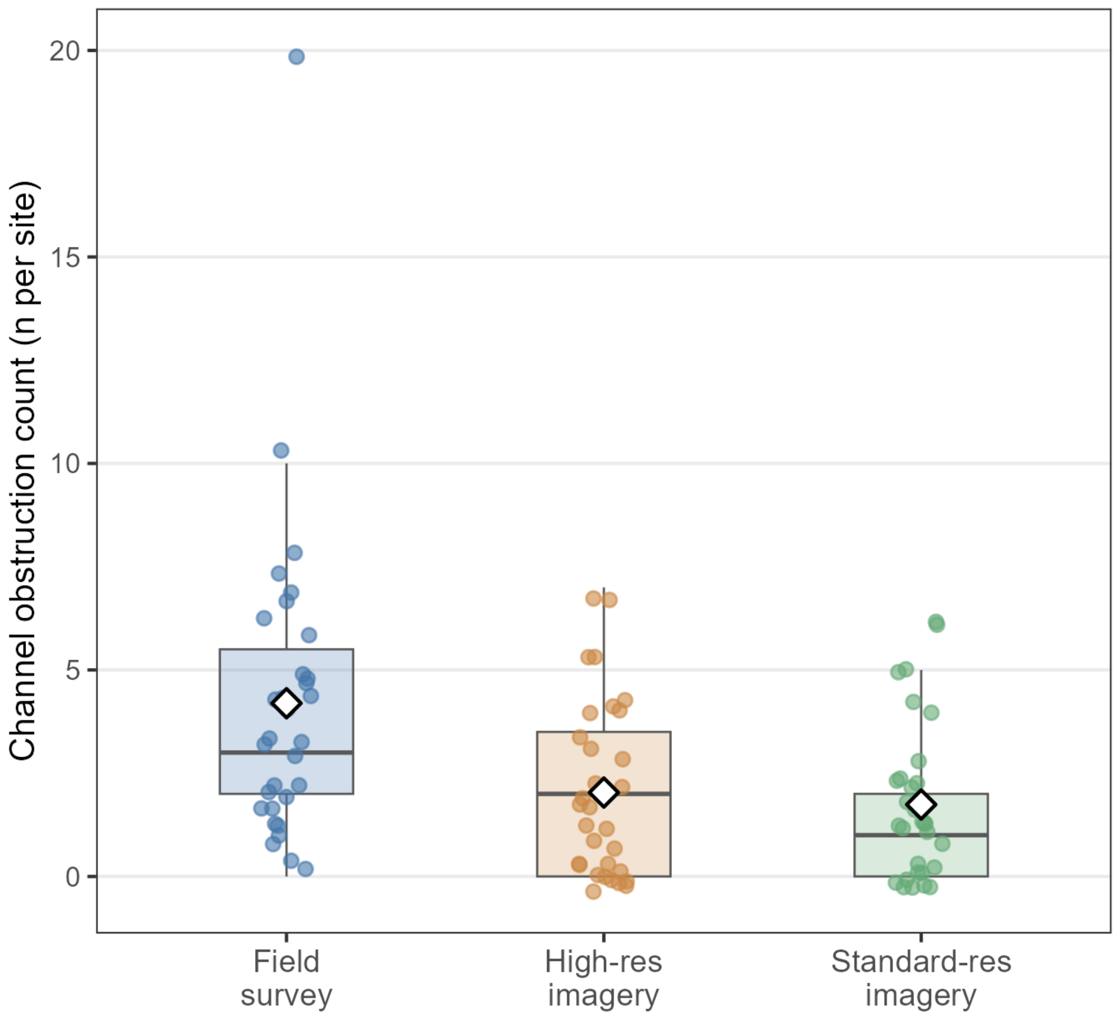

Figure 20. Distribution of channel obstruction counts per monitoring site derived from field survey, high-resolution imagery, and standard-resolution imagery (n = 31 sites). Boxes represent the interquartile range (IQR), centre lines the median, and diamonds the mean. Whiskers extend to 1.5 × IQR, and points represent individual sites.

Table 12. Site-level agreement statistics for channel obstruction counts derived from high-resolution imagery and standard-resolution imagery relative to field survey observations (*n* = 31)

Indicator	**Method**	**Mean difference**	**Holm-adjusted *P***	**MAE**	**RMSE**	**Correlation (*r*)**
Channel obstruction count (*n* per site)	High-resolution imagery	–2.2	0.001	2.5	4.0	0.47
	Standard-resolution imagery	–2.5	<0.001	2.6	4.0	0.55

Notes: Mean difference was calculated as imagery minus field survey, with positive values indicating overestimation and negative values indicating underestimation relative to the field survey. Bias is presented with its 95% confidence interval. Paired *t*-tests with Holm-adjusted *P* values indicate whether the mean bias differed significantly from zero. MAE = mean absolute error; RMSE = root mean square error.

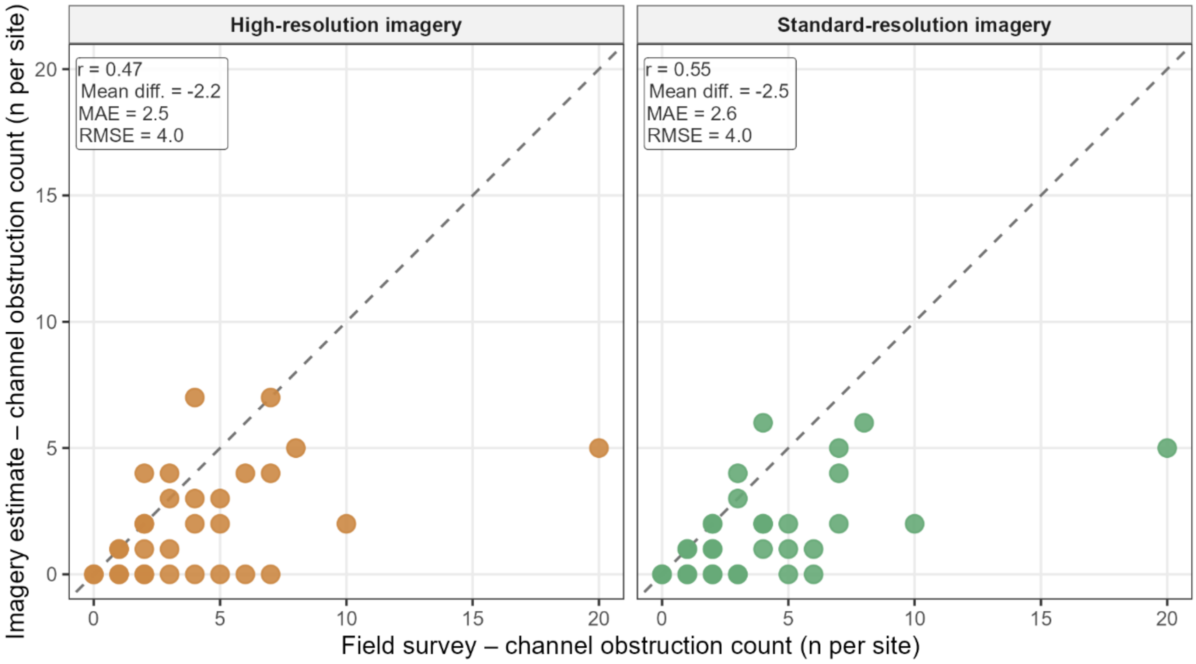

Figure 21. Site-level comparison of channel obstruction counts per monitoring site estimated from high-resolution imagery (left) and standard-resolution imagery (right) relative to field survey estimates. The dashed line indicates perfect agreement (1:1), and panel annotations summarise Pearson's correlation coefficient (r), bias, mean absolute error (MAE), and root mean square error (RMSE) relative to the field survey.

5.3 Interpretation of monitoring performance

The agreement analyses demonstrate that no single monitoring approach consistently outperformed the others across all streambank and riparian characteristics. Instead, monitoring performance depended on the type of characteristic being assessed, the level of detail required, and the spatial resolution of the imagery. The following sections examine these factors in more detail, including attribute-specific performance, repeatability, and the ability of each method to differentiate riparian condition.

5.3.1 Attribute-specific performance

The agreement analyses demonstrated that monitoring performance depended strongly on the streambank or riparian characteristic being assessed. Fencing, woody vegetation extent, mean riparian vegetation width, and overall stream shading showed the strongest overall agreement between methods. High-resolution imagery produced estimates that closely matched those obtained from the field survey, with relatively small mean differences (−7.8 percentage points to +0.8 percentage points), low MAE values (5.9–11.2 percentage points or 1.3 m for vegetation width), and strong site-level correlations (r = 0.84–0.95) (Tables 5 and 7). Standard-resolution imagery generally produced larger errors and weaker correlations (r = 0.72–0.86), but nevertheless reproduced the broad patterns observed across the monitoring sites (Figures 8, 13–15).

The paired t-tests distinguished attributes with significant mean differences between methods, suggesting potential systematic bias, from those for which differences reflected primarily random variation. Mean differences for fenced bank length, effective fencing and woody vegetation assessed using high- and standard-resolution imagery were not significantly different from zero, indicating no evidence of over- or underestimation relative to the field survey, despite variability among individual sites. In contrast, both imagery methods produced significantly greater estimates of mean riparian vegetation width and complete stream shading, while high-resolution imagery produced significantly lower estimates of overall stream shading. Both imagery approaches also produced significantly lower streambank erosion estimates, whereas standard-resolution imagery also produced significantly lower estimates of stock pugging. These results indicate that differences were most evident for characteristics requiring finer interpretation or direct assessment of site condition.

Agreement was substantially lower for characteristics requiring assessment of condition, function, or subtle geomorphic features. Streambank erosion and stock pugging showed the weakest agreement between methods, with a mean difference of 11.5 percentage points (RMSE = 23.2) for erosion between high-resolution imagery and the field survey (Table 9). Similarly, standard-resolution imagery produced substantially larger mean differences and errors for stock pugging and significantly lower levels of pugging relative to the field survey. Channel obstruction counts were also significantly lower for both imagery methods. Scatterplots demonstrated that imagery generally identified the presence of erosion and pugging but consistently recorded lower proportions of bank length affected, particularly at sites with greater levels of erosion or pugging (Figure 19).

In contrast, the performance of individual attributes reflected the complementary strengths of field-based and imagery-based observations. Characteristics describing clearly identifiable physical features or overall spatial extent were reproduced consistently from aerial imagery. For example, estimates of total woody vegetation extent differed by less than one percentage point between methods (32.4–32.7% of bank length), despite larger differences in the classification of individual woody vegetation types (Figure 9). Likewise, although mean riparian vegetation width was slightly but significantly greater for imagery-based assessments, overall agreement remained high (MAE = 1.3 m; $r = 0.84$). Similarly, estimates of overall stream shading showed strong agreement ($r = 0.86$), despite imagery tending to classify complete and incomplete canopy cover differently from field surveys. These results indicate that aerial imagery provides reliable estimates of riparian characteristics defined primarily by their spatial extent and continuity, even where small differences occur.

Conversely, characteristics requiring assessment of condition or fine-scale characteristics were more difficult to assess consistently from aerial imagery. Both imagery approaches recorded considerably less streambank erosion than the field survey (9.5–12.8% compared with 24.3% of bank length). High-resolution imagery produced similar overall estimates of stock pugging compared to the field survey, whereas standard-resolution imagery recorded substantially lower levels of pugging and classified a greater proportion of bank length as unobserved (Figures 18,19, and 21). Similarly, disagreement in riparian vegetation width most commonly occurred between adjacent width classes rather than fundamentally different categories, and differences in stream shading largely reflected the distinction between complete and incomplete canopy cover rather than the overall presence of shading (Table 7). These patterns suggest that disagreement was generally associated with boundary interpretation, subtle or transient features, or limitations imposed by the aerial viewing perspective rather than an inability to identify the broad characteristics of riparian condition.

Image resolution further influenced monitoring performance. Across almost all attributes, high-resolution imagery agreed more closely with the field survey observations than standard-resolution imagery did, producing smaller mean differences, lower MAE and RMSE values, and stronger correlations (Tables 5, 7, 9, and 12). The differences were relatively modest for broad spatial characteristics such as fencing and woody vegetation extent but became progressively larger for characteristics requiring finer discrimination, including woody vegetation type, vegetation-width categories, streambank erosion, pugging, and channel obstructions (Figures 9, 10, 16, 17, and 20). Nevertheless, the site-level distributions and scatterplots consistently showed that both imagery approaches reproduced the broad gradient in riparian condition across the 31 monitoring sites, with disagreement becoming greatest where characteristics occurred as small, patchy, visually obscured, or short-lived features.

Overall, the results demonstrate that no single monitoring method was the most appropriate for all streambank and riparian characteristics. Rather, each method exhibited strengths for different attribute types. Field surveys provided the greatest sensitivity for assessing condition, disturbance, and other fine-scale characteristics, whereas high-resolution imagery provided a reliable and consistent alternative for assessing the spatial extent and distribution of many riparian attributes. Standard-resolution imagery remained capable of distinguishing broad differences in riparian condition, but showed reduced accuracy for characteristics requiring fine-scale interpretation. Consequently, the most appropriate monitoring approach depends on both the objectives of the monitoring programme and the riparian characteristics being assessed.

5.3.2 Repeatability and consistency

Formal inter- and intra-observer repeatability assessments, involving independent reassessment of the field surveys and imagery by separate assessors, were beyond the scope of this study. Nevertheless, several measures were implemented to maximise consistency between assessments. A primary assessor undertook aerial imagery interpretation. and field surveys completed by teams of two or three assessors using a standardised protocol. Following data collection, both the imagery and field data sets underwent quality assurance to verify interpretation, resolve classification inconsistencies, and ensure consistent application of the survey protocols across all sites. Consequently, the agreement analyses presented in section 5.2, together with observations made during method development, implementation, and quality assurance, provide useful insight into the factors most likely to influence assessment consistency.

Across all three monitoring approaches, consistency was generally highest for characteristics based on clearly identifiable physical features (Table 13). This was reflected in the agreement analyses (section 5.2), where fenced bank length (r = 0.84 and 0.72), woody vegetation extent (r = 0.95 and 0.79), and overall stream shading (r = 0.86 for both imagery methods) exhibited the strongest agreement between methods. These characteristics could generally be identified with relatively little assessor interpretation because they were defined by distinct physical features or overall spatial extent (Figure 22). Consistent with this, paired *t*-tests indicated no significant systematic differences between imagery- and field-derived estimates for these characteristics, indicating that differences between methods were largely attributable to random variation (or land-use change between imagery acquisition and field visits) among sites rather than mean difference.

In contrast, repeatability was lower for characteristics requiring interpretation of boundaries, condition, or subtle physical features. Riparian vegetation width, vegetation type, streambank erosion, stock pugging, and channel obstructions, all required greater judgement and therefore showed greater variability between assessments (Figure 23). These characteristics commonly involved diffuse riparian boundaries, gradual transitions between vegetation classes, subtle changes in erosion, or subjective evaluation of thresholds, such as distinguishing complete from incomplete stream shading (Figure 24). Several of these attributes also exhibited mean differences between imagery and field surveys. For example, imagery-based assessments consistently estimated greater mean riparian vegetation widths and higher levels of complete stream shading relative to field surveys, whereas streambank erosion and channel obstruction counts were consistently lower, reflecting limitations imposed by the aerial viewing perspective in addition to assessor interpretation.

Table 13. Principal sources of uncertainty affecting assessment consistency

Attribute	Principal sources of uncertainty
Fence type	Vegetation obscuring fences; image resolution; judgement on whether a fence is a riparian fence
Fence effectiveness	Judgement of stock exclusion effectiveness; temporary fencing; vegetation concealment
Vegetation extent	Delineation of riparian boundary; diffuse vegetation margins
Vegetation width	Definition of channel edge and outer riparian boundary; estimation of distances
Vegetation type	Species discrimination; mixed vegetation; image resolution
Stream shading	Distinguishing complete from partial canopy cover; image resolution
Streambank erosion	Vegetation concealment; viewing perspective; subtle erosion features; determining active vs recent
Stock pugging	Temporary site conditions; vegetation cover; subjective whether <50% or >50%
Adjacent land use	Genuine land-use change between survey dates; whether there is a change in land use adjacent to channel
Channel and bank characteristics	Poorly defined channels; multiple bank surfaces; floodplain transitions

Figure 22. Examples of stream reaches expected to exhibit high assessment repeatability. Clearly defined riparian margins, fences (left), and continuous woody vegetation (right) can be identified with minimal assessor interpretation.

Figure 23. Examples of stream reaches requiring greater assessor interpretation. The left image illustrates assessment of fence effectiveness where vegetation structure and riparian structure influence interpretation of stock exclusion. The right image shows streambank erosion and stock pugging, which are subtle, fine-scale characteristics that are more difficult to identify consistently from aerial imagery than from field observations.

Figure 24. Example of subjectivity in determining stream shading, partly influenced by seasonality of deciduous trees: even where complete canopy cover is clear from imagery (right), the field survey indicates some light is getting through so requires more judgement to determine if it would be complete or partial shading (left).

A significant source of uncertainty was not the monitoring method itself, but the complexity of the stream environment (Figure 25). Assessment was generally straightforward where channels, banks, riparian margins, and adjacent land uses were clearly defined. Interpretation became more challenging where channel morphology was complex, floodplains merged gradually with adjacent land uses, multiple bank surfaces were present, or modified channels lacked clearly defined margins. Similarly, dense vegetation often obscured streambanks and fences, while subtle erosion, recent disturbance, and temporary stock impacts required assessors to distinguish between natural variability and meaningful change.

Each monitoring approach addressed these sources of uncertainty differently. Field surveys benefited from direct observation and allowed assessors to inspect features from multiple viewpoints, reducing uncertainty for characteristics concealed from aerial imagery. However, field assessments also relied on judgement when defining riparian boundaries, assigning vegetation classes, or evaluating fence effectiveness, making these assessments inherently more subjective, even among trained and experienced surveyors. High-resolution imagery provided a permanent visual record that could be revisited, measured consistently within a GIS environment, and interpreted using stereo imagery to improve assessment of bank morphology, vegetation structure, and topographic context. Standard-resolution imagery followed the same assessment workflow but provided substantially less visual information (spatial and spectral); consequently, characteristics requiring finer-scale interpretation, including vegetation-width classes, woody vegetation classes, fencing effectiveness, streambank erosion and pugging, and channel obstructions, showed greater disagreement than high-resolution imagery in the agreement analyses (section 5.2).

Figure 25. Examples of channel settings that increase interpretation uncertainty. Complexity arising from diffuse floodplain margins, multiple bank surfaces, poorly defined channels, or extensive vegetation increases the importance of assessor judgement regardless of monitoring approach.

In addition to interpretation uncertainty, all three monitoring approaches were subject to measurement uncertainty associated with the delineation of streambank segments and riparian boundaries. In the field, measured lengths were influenced by GNSS positional accuracy and by the survey path, which followed one streambank rather than the channel centreline. Consequently, measured distances could vary depending on whether the survey followed the inside or outside of channel bends. Similarly, imagery-based assessments depended on how streambank segments and attribute boundaries were digitised within the GIS environment. Although these sources of measurement uncertainty are generally small relative to the length of the surveyed reaches, they are unavoidable and contribute to differences between methods, particularly for short or highly fragmented riparian features.

Overall, repeatability depended more on the complexity of the stream environment and the degree of interpretation required than on the monitoring method itself. Characteristics based on clearly identifiable physical features were expected to exhibit high repeatability regardless of assessment method, whereas characteristics requiring subjective interpretation of riparian boundaries, vegetation type, erosion severity, fence effectiveness, or stream visibility were inherently more susceptible to assessor variability. The agreement analyses further demonstrated that some of these characteristics also exhibited differences between imagery and field surveys, particularly for streambank erosion, channel obstruction counts, vegetation width, and complete stream shading. The qualitative assessment of expected repeatability (Table 14) reflects these observations, with high-resolution imagery generally providing greater consistency than standard-resolution imagery for characteristics requiring finer-scale interpretation.

Table 14. Comparative assessment of consistency of the three monitoring methods for monitoring streambank and riparian characteristics

Attribute	Field survey	High-resolution imagery	Standard-resolution imagery	Comments
Fence presence	Very good	Very good	Good	High agreement between methods; easily identifiable where visible.
Fence effectiveness	Good	Good	Moderate	Requires judgement of stock exclusion and fence condition.
Riparian vegetation extent	Good	Very good	Good	Strong agreement for broad vegetation cover.
Riparian vegetation width	Good	Very good	Moderate	Imagery provides consistent spatial measurements where boundaries are well defined.
Vegetation type	Very good	Good	Moderate	Resolution influences ability to distinguish vegetation classes.
Stream shading	Good	Good	Moderate	Greatest differences between complete and partial shading.
Streambank erosion	Very good	Moderate	Limited	Fine-scale erosion and undercutting difficult to identify remotely.
Stock pugging	Very good	Moderate	Limited	Temporary condition; frequently obscured from aerial imagery.
Adjacent land use	Very good	Very good	Very good	Broad land-use classes readily identified by all methods.
Channel and bank characteristics	Good	Good	Moderate	Depends on channel complexity and visibility.

Notes: Ratings represent a qualitative synthesis of the quantitative agreement analyses (section 5.2), together with observations made during method development, assessor training, quality assurance, and implementation. They are intended to provide a comparative assessment of consistency rather than measured repeatability.

5.3.3 Ability to identify riparian characteristics and riparian condition

Although the three monitoring approaches differed in their agreement for individual streambank and riparian characteristics (section 5.2), all were capable of distinguishing broad differences in riparian condition across the study sites. Characteristics such as fencing extent, woody vegetation cover, vegetation width, and stream shading showed relatively high agreement between methods, with high-resolution imagery producing strong correlations with the field survey (r = 0.84–0.95) and standard-resolution imagery generally reproducing the same overall patterns despite larger errors. Paired *t*-tests further demonstrated that several broad-scale characteristics, including fenced bank length and woody vegetation extent, exhibited no significant systematic differences between imagery- and field-derived estimates. Consequently, reaches with extensive riparian vegetation, continuous fencing and stock exclusion, and well-developed woody cover were consistently distinguished from reaches with limited riparian protection, regardless of the monitoring approach.

Differences between monitoring approaches became more apparent as the level of detail required increased. The field survey consistently provided the greatest amount of information, allowing assessors to identify fine-scale characteristics such as vegetation type, stock pugging (Figure 26), and subtle streambank erosion that were not identified as readily in high-resolution imagery and that were difficult or impossible to identify reliably from aerial imagery. These additional field observations improved confidence in the interpretation of riparian condition and enabled assessment of characteristics that depended on condition rather than simply presence or extent.

High-resolution imagery retained much of this discriminatory ability while providing a consistent overhead perspective of the entire stream reach. The agreement analyses showed that high-resolution imagery closely reproduced field survey estimates for most structural riparian characteristics, including effective fencing, woody vegetation extent, vegetation width, and overall stream shading, while also providing sufficient detail to identify many finer-scale features such as fence effectiveness, vegetation structure, obvious erosion and pugging, and stock within paddocks. Nevertheless, the paired *t*-tests demonstrated that some characteristics exhibited consistent directional differences despite otherwise strong agreement. Mean riparian vegetation width and complete stream shading was higher, whereas streambank erosion, overall stream shading, and channel obstruction counts were lower relative to the field survey estimates. These results indicate that high-resolution imagery generally preserved the relative differences among sites while introducing small biases for certain attributes when summarised across the study sites.

Figure 26. Examples of pugging observable during the field survey but difficult to identify from imagery, particularly standard-resolution imagery.

Standard-resolution imagery remained effective for distinguishing broad differences in riparian condition but provided substantially less information than either the field survey or high-resolution imagery for more subtle characteristics. The lower spatial resolution reduced confidence in identifying narrow riparian buffers, vegetation composition, fence effectiveness, subtle erosion features including pugging, and other small or visually complex characteristics (Figure 27). In addition to spatial resolution, differences in spectral resolution may also have influenced image interpretation by affecting the visibility and contrast of subtle riparian features, although this was not evaluated separately. These observations are consistent with the quantitative agreement analyses, where standard-resolution imagery generally produced larger biases, higher MAE and RMSE values, and weaker correlations than high-resolution imagery, and with the qualitative assessment presented in Table 15, reduced ability to discriminate finer-scale riparian characteristics.

In addition to image resolution, the conditions under which aerial imagery was acquired also influenced the ability to identify streambank and riparian characteristics. Sun angle, illumination, and shadowing substantially affected the visibility of streambank morphology, vegetation structure, fences, and other subtle riparian features. Although shadows can obscure some characteristics, they often enhance interpretation by increasing contrast and improving the three-dimensional expression of banks, vegetation, fences, and surface relief. Seasonal differences in vegetation condition and canopy cover can similarly influence feature visibility. Consequently, image resolution alone does not determine the amount of information available for interpretation. As illustrated in Figure 28, the higher-resolution (2.5 cm) imagery provided less interpretability of some streambank and riparian characteristics than the lower-resolution (12.5 cm) imagery (but higher than the standard resolution) because differences in illumination and shadowing reduced the visibility of topographic relief and vegetation structure.

Overall, the results indicate that the principal difference between monitoring approaches lies in the amount of finer-scale information that can be resolved rather than their ability to distinguish broad riparian condition. Field surveys provided the highest level of detail and remained the most effective approach for assessing fine-scale condition and functional characteristics. High-resolution imagery captured most structural riparian characteristics with comparatively little loss of information, and generally reproduced the broad gradients in riparian condition, although some attributes exhibited systematic differences relative to field surveys. Although stereo imagery was not always required in this investigation, it was useful for checking streambank and riparian characteristic queries raised during the high-resolution image analysis, including verification of fencing effectiveness, vegetation type and height, streambank erosion type and the presence and nature of channel obstructions. The relative ability of the three monitoring approaches to differentiate individual riparian characteristics is summarised in Table 15.

Figure 27. An example illustrating the influence of image resolution and survey perspective on riparian assessment. High-resolution imagery (top left) shows individual vegetation types (e.g. mānuka/kānuka, identifiable fences (Fence A and Fence B) as well as type, and narrow riparian features. In contrast, standard-resolution imagery (top right) provides only broad vegetation patterns and while Fence A is observable, Fence B is not. The field perspective (bottom) provides additional information on vegetation composition, and other characteristics that are less visible from an aerial perspective.

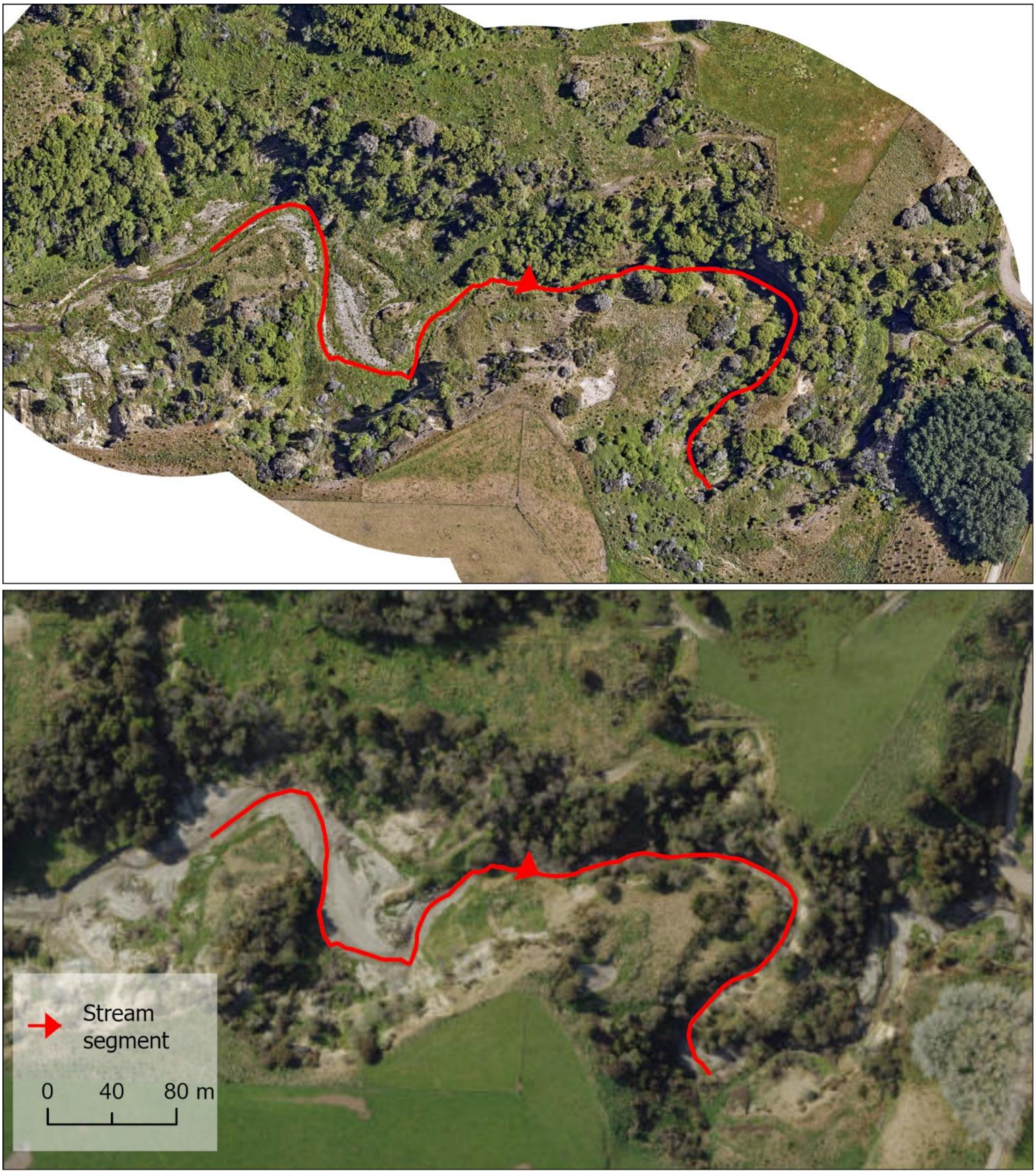

Figure 28. An example demonstrating that image resolution alone does not determine the amount of information available for aerial image interpretation. Despite its finer spatial resolution (2.5 cm), the top image is more difficult to interpret topography and vegetation structure than a lower 12.5 cm resolution image (bottom) because differences in illumination and shadowing, as well as seasonality, influence the visibility of physical features.

Table 15. Relative ability of field survey, high-resolution aerial imagery (2.5 cm), and standard-resolution aerial imagery (25 cm) to differentiate individual streambank and riparian characteristics

Attribute group	Field survey	High-resolution imagery*	Standard-resolution imagery
Fence type (presence)	High	High	Moderate
Fence effectiveness	High	Moderate–High	Low
Riparian vegetation extent	Moderate–High	High	Moderate
Vegetation type	High	Moderate–High	Low–Moderate
Vegetation width	Moderate–High	High	Moderate
Stream shading	High	Moderate–High	Moderate–High
Streambank erosion	High	Moderate	Low–Moderate
Stock disturbance	High	Moderate	Low
Channel obstructions	High	Moderate	Low–Moderate

Notes: Ratings are based on the quantitative agreement analyses (section 5.2) together with qualitative assessment of information content, assessor confidence, and feature visibility during method implementation. * Stereo imagery has the potential to further improve streambank and riparian characteristic differentiation.

5.4 Practical implementation

5.4.1 Resource requirements

The three monitoring approaches differed in their resource requirements, implementation costs, efficiency, and scalability (Table 16). These requirements extended beyond the time needed to assess an individual site and included planning, logistics, equipment, imagery acquisition, data processing, quality assurance, and the ongoing effort required to repeat monitoring over time.

Field surveys represented the most resource-intensive approach (Tables 16 and 17). Although assessment of an individual site typically required approximately 1 hour, substantially greater effort was associated with planning, landowner liaison, travel, health and safety procedures, field preparation, post-processing, and quality assurance. We assessed approximately five sites per full day with a two-person team; however, longer travel distances, poor site accessibility, adverse weather, and complex channel conditions could reduce this to four sites per day, consistent with operational experience at WRC (WRC, pers. comm.). Equipment requirements were relatively modest, comprising a low-cost GNSS receiver, positioning subscription, tablet or smartphone, and standard field equipment. Establishing a monitoring programme also required developing digital survey forms, configuration of GNSS workflows, staff training, and quality assurance procedures. Indicative implementation costs ranged from approximately NZ$265–$430 per site under a student- or intern-led staffing model to NZ$515–$830 per site when undertaken by a standard salaried scientist or technician (Table 17).

High-resolution aerial imagery substantially reduced labour requirements by eliminating travel, landowner liaison, and time in the field. Once suitable imagery had been acquired and prepared, desktop assessments typically required 30–60 minutes per site, allowing approximately five to eight sites to be assessed per day depending on site complexity and the level of quality assurance undertaken. Implementation costs depended primarily on the availability of suitable imagery. Commissioning dedicated 2.5 cm orthophotography for the TANK study area was estimated to cost approximately NZ$500 per site (HBRC, pers. comm.). The same aerial acquisition also provides the overlapping raw image pairs required for stereo interpretation. Consequently, indicative implementation costs ranged from approximately NZ$560–$625 per site under a student- or intern-led staffing model to NZ$620–$750 per site when undertaken by a standard scientist or technician (Table 17). However, stereo interpretation required additional photogrammetric processing, specialised GIS software, higher-specification computing hardware, and staff trained in stereo image interpretation.

Table 16. Comparison of indicative implementation requirements, costs, efficiency, and scalability of field survey, high-resolution imagery, and standard-resolution imagery approaches

Criterion	Field survey	High-resolution imagery	Standard-resolution imagery
Site assessment time	c. 60 min/site (+ travel)	c. 30–60 min/site	c. 15–45 min/site
Daily productivity	4–6 sites/day	5–8 sites/day	7–10 sites/day
Landowner access required	Required	None	None
Weather dependent	High	None	None
Travel requirements	High	None	None
Equipment requirements	GNSS GPS, vehicles, field equipment, GIS software	GIS software, stereo workstation and software, imagery	GIS software, imagery
Specialist skills	Field survey, riparian assessment and interpretation training	GIS editing skills and imagery interpretation (2D and 3D) training	GIS editing, and imagery interpretation training
Imagery acquisition costs	None	High	Low to negligible*
Data processing effort	Moderate–High	Moderate–High	Low–Moderate
Scalability	Low	Moderate	High
Repeat survey practicality	Low	Moderate	High
Indicative implementation cost	High	Moderate	Low
Future repeatability	Moderate	High	High

Notes: Estimates are based on experience gained during project implementation and are intended to provide relative rather than absolute measures of resource requirements. *In many regions, standard-resolution aerial imagery is already available through existing regional council, LINZ, or commercial aerial imagery programmes.

Standard-resolution imagery required the lowest overall implementation effort where suitable imagery was already available through regional councils, LINZ, or commercial providers. Desktop assessment followed essentially the same workflow as the high-resolution imagery approach but required only standard GIS software. Consequently, implementation costs were substantially lower while retaining many of the operational efficiencies associated with desktop assessment.

The principal distinction between the three approaches was the trade-off between labour requirements and imagery acquisition costs (Tables 16 and 17). Field surveys required the greatest investment in personnel time, logistics, and ongoing operational effort but provided the highest level of observational detail. High-resolution imagery substantially reduced labour requirements, but shifted much of the implementation cost to acquisition of suitable aerial imagery. Where high-resolution imagery was already available through existing regional aerial survey programmes or shared across multiple applications, imagery acquisition costs could be largely avoided, substantially improving the cost-effectiveness of desktop assessments. Standard-resolution imagery required the fewest resources overall and offered the greatest scalability, although with reduced ability to consistently identify finer-scale streambank and riparian characteristics.

Overall, differences in implementation requirements become increasingly important as monitoring programmes increase in scale. Although the indicative per-site implementation costs of field surveys and commissioned high-resolution imagery overlapped depending on the staffing model adopted, the underlying cost structures differed substantially. Field survey costs were dominated by personnel time, travel, and logistics, resulting in implementation effort that increased approximately in proportion to the number of sites surveyed. In contrast, imagery acquisition represents a largely upfront investment that can be distributed across many monitoring sites, reused for repeat assessments, or shared across multiple projects. Consequently, the relative cost-effectiveness of imagery-based monitoring is expected to improve as programme scale increases, particularly where suitable imagery is already available.

Table 17. Indicative implementation effort, person-hours, and per-site costs for field survey, high-resolution imagery, and standard-resolution imagery monitoring approaches

Cost component	Field survey per site	High-resolution imagery per site	Standard-resolution imagery per site
Site preparation	0.5–1.0 hr	0.2–0.5 hr	0.2–0.5 hr
Landowner liaison	1.0–2.0 hr	–	–
Travel and logistics	1.0–2.0 hr	–	–
Assessment	2.0 hr	0.5–1.0 hr	0.25–0.75 hr
Post-processing & QA	0.5–1.0 hr	0.5–1.0 hr	0.3–0.75 hr
Total labour effort	5.0–8.0 hr	1.2–2.5 hr	0.75–2.0 hr
Labour cost: student- or intern-led at $50/hr	$250–$400	$60–$125	$40–$100
Labour cost: standard scientist at $100/hr	$500–$800	$120–$250	$75–$200
Vehicle & travel	c. $15–$30	–	–
Imagery acquisition	–	c. $500	Assuming already available
Implementation cost: student- or intern-led	c. $265–$430	c. $560–$625	c. $40–$100
Implementation cost: standard scientist	c. $515–$830	c. $620–$750	c. $75–$200

Notes: Implementation costs are indicative and intended for order-of-magnitude comparison only.

Labour costs assume indicative charge-out rates of NZ$50/hr (student/intern) and NZ$100/hr (scientist), inclusive of supervision and organisational overheads.

Actual costs will vary with staffing, programme scale, travel, and imagery availability. High-resolution imagery costs assume dedicated 2.5 cm aerial photography.

A dash (–) indicates that no sites were classified in that category.

5.4.2 Operational considerations

Although imagery-based monitoring reduced implementation costs, particularly labour costs, compared with field surveys (section 5.4.1), each monitoring approach was subject to different operational constraints that influenced where, when, and how assessments could be undertaken. These constraints affected survey logistics, assessor safety, scheduling flexibility, and the consistency of long-term monitoring programmes.

Field surveys were the most operationally demanding approach. Successful implementation depended on obtaining landowner permission, arranging site access, coordinating field logistics, and maintaining appropriate health and safety procedures. Locating landowners and securing access permissions often required considerable administrative effort, particularly where property ownership was fragmented or difficult to determine. In some cases contact details could not be obtained. Once access had been obtained, surveys remained dependent on weather conditions, river flows, site accessibility, and channel complexity. Dense vegetation, steep banks, stock movements, or physical barriers occasionally required survey routes to be modified or prevented complete assessment of some reaches. Field implementation also required two staff members in order to satisfy organisational health and safety requirements, with daily productivity often constrained more by travel and logistics between sites than by the time required to complete individual site assessments.

Where landowners were notified before site visits, there was the potential for temporary management changes, such as removing stock or installing temporary fencing prior to assessment. These changes may influence observations because surveys are intended to represent typical site conditions, and several examples of this were observed during this study. Maintaining long-term access also presents an ongoing challenge. Changes in land ownership or access agreements may prevent repeat surveys at established monitoring sites, resulting in the loss of long-term records and/or landowner relationships, and requiring new sites to be established, thereby reducing the value of previous monitoring investment.

Imagery-based monitoring eliminated many of these operational constraints. Desktop assessments could be undertaken from any location without travel and were not constrained by landowner access permissions, site accessibility, or weather, river flow, and other field conditions. However, weather and environmental conditions can influence the timing and quality of aerial image acquisition. This substantially increased scheduling flexibility, allowing assessments to be undertaken whenever staff were available and enabling large numbers of sites to be assessed efficiently across broad geographical areas.

The principal operational constraint for imagery-based monitoring was the availability and suitability of aerial imagery. High-resolution assessments generally required dedicated aerial acquisition or access to suitable existing data sets, whereas standard-resolution imagery was widely available through regional councils, LINZ, and commercial providers. However, a major operational advantage of imagery-based monitoring was the creation of a permanent visual record. Unlike field observations, which rely primarily on field notes and limited photography, aerial imagery can be revisited repeatedly during interpretation, quality assurance, assessor training, and subsequent monitoring. Assessors were able to review previous decisions, independently verify interpretations, compare historical imagery where available, and undertake more consistent quality assurance. This permanent visual archive will also be a valuable resource for future comparisons and assessments of streambank and riparian characteristics, as well as for scientific studies investigating changes associated with specific environmental events. If additional characteristics are required, the historical imagery could be reanalysed to produce a consistent record.

5.4.3 Technical requirements

The three monitoring approaches differed not only in their implementation requirements but also in the technical capability required for data collection, processing, management, and future automation (Table 18). These differences influence the ease with which monitoring programmes can be established, maintained, quality assured, integrated within existing GIS systems, and expanded over time.

Field surveys required relatively modest technical capability during data collection. Once digital Survey123 forms and survey protocols had been established, observations could be collected efficiently using standard tablets and GNSS receivers. However, initial development of digital survey forms, configuration of GNSS, and ongoing management of positioning subscriptions required technical expertise. Following data collection, field observations required additional processing to generate continuous segments, calculate chainages, summarise segment lengths, and derive reach-scale metrics before analysis.

The imagery-based approaches shifted much of the technical complexity from field data collection to image interpretation and spatial analysis. Both approaches used a common GIS-based workflow in which stream centreline data sets, streambank boundaries, and mapped features were integrated to produce spatially referenced streambank segments for subsequent analysis. These outputs were inherently spatial and readily integrated into existing GIS databases, simplifying downstream analysis, reporting, and long-term data management.

High-resolution imagery required the greatest technical capability. Interpretation required experienced GIS users familiar with aerial image interpretation, while stereo interpretation also required stereo viewing hardware, access to the overlapping aerial photographs acquired during the same survey, and staff trained in three-dimensional image interpretation. These additional requirements increased implementation complexity but improved interpretation of streambank morphology, fencing effectiveness, vegetation structure/height, streambank erosion, the presence and nature of channel obstructions, and other three-dimensional characteristics that were difficult to distinguish reliably from orthophotography alone.

Standard-resolution imagery followed essentially the same GIS workflow but required less specialised technical capability due to the absence of stereo interpretation. Interpretation could generally be undertaken using standard GIS software without stereo viewing hardware or specialist image interpretation skills, making implementation technically simpler while maintaining compatibility with the same spatial data management framework used for high-resolution assessments.

The imagery-based approaches also provide substantially greater opportunities for future automation. Many of the structural characteristics assessed in this study – including riparian vegetation extent and width, stream shading, fencing, and potentially some aspects of streambank erosion – could be derived or supported using object-based image analysis, machine learning, or artificial intelligence. As imagery resolution, computing capability, and automated feature extraction continue to improve, desktop interpretation is likely to become increasingly efficient while maintaining consistent application of classification rules. In contrast, characteristics requiring direct assessment of condition, function, or recent disturbance, such as livestock impacts, fence effectiveness, active erosion processes, or functional assessments of streambank condition, are likely to continue to rely primarily on manual interpretation or field observation.

Overall, field surveys required the greatest technical effort for post-processing of observations, whereas high-resolution imagery required the greatest technical expertise during interpretation. Standard-resolution imagery represented the simplest technical implementation pathway while remaining fully compatible with modern GIS-based monitoring frameworks. Consequently, the technical complexity of the three approaches reflects a shift from field-based expertise towards increasingly sophisticated spatial analysis, digital data management, and future automated interpretation.

Table 18. Comparison of technical requirements, data management considerations, and future automation potential for field survey, high-resolution imagery, and standard-resolution imagery approaches

Criterion	Field survey	High-resolution imagery	Standard-resolution imagery
Primary technical expertise	Field survey and GNSS data collection	GIS, aerial image interpretation, stereo interpretation	GIS and aerial image interpretation
GIS skills required	Moderate	High	Moderate
Data collection platform	Survey123 and GNSS	Desktop GIS	Desktop GIS
Data processing effort	Moderate–High (segmentation, chainage, summaries)	Moderate	Moderate
Specialist software	Survey123, ArcGIS Pro	ArcGIS Pro (Image Analyst), stereo viewing software	ArcGIS Pro/QGIS
Specialist hardware	GNSS receiver and tablet	Stereo-capable workstation (or monitor) and suitable graphics hardware	Standard desktop computer
Quality assurance capability	Moderate (field notes and photographs)	High (imagery permanently available)	High (imagery permanently available)
Data reproducibility	Moderate	High	High
GIS compatibility	Moderate	High	High
Long-term data storage	Good	Excellent	Excellent
Ability to revisit assessments	Poor	Excellent	Excellent
Potential for automation	Low–Moderate	High	High

Notes: High-resolution imagery includes a stereo interpretation component. If stereo imagery is not used, the technical requirements for many assessment criteria are similar to those for standard-resolution imagery

5.5 Synthesis of monitoring performance

The comparative assessment demonstrated that the three monitoring approaches occupy different positions along a trade-off between information content, implementation requirements, technical complexity, repeatability, and scalability (Table 19). Rather than identifying a single monitoring approach that consistently outperformed the others, the results indicate that each approach possesses distinct strengths and limitations, making them suited to different monitoring objectives.

Field surveys provided the highest level of observational detail and remain the only approach capable of consistently assessing characteristics requiring direct inspection or functional interpretation, especially when visibility is compromised by vegetation, including livestock access, fence effectiveness, stock pugging, subtle streambank erosion, the presence and nature of channel obstructions, and other site-specific observations that were not reliably identifiable from aerial imagery. These advantages came at the cost of substantially greater operational effort through landowner liaison, travel, health and safety requirements, field logistics, and post-processing of observations.

High-resolution imagery provided the strongest balance between information content and implementation efficiency. Agreement with field surveys was high for most structural riparian characteristics, including fencing extent, woody vegetation, riparian vegetation width, and overall stream shading, with relatively small mean differences, low MAE and RMSE values, and strong site-level correlations. Several attributes, including fenced bank length, effective fencing, and woody vegetation, exhibited no significant differences to field survey estimates. In contrast, mean riparian vegetation width, complete stream shading, streambank erosion, and channel obstruction counts exhibited mean differences despite generally good overall agreement, reflecting differences in attribute interpretation rather than an inability to distinguish broad patterns in riparian condition.

Standard-resolution imagery retained the ability to distinguish broad patterns in riparian condition while requiring the lowest implementation effort where suitable imagery was already available. However, lower spatial resolution reduced confidence in identifying narrow riparian buffers, vegetation composition, fence effectiveness, streambank erosion, stock disturbance, and other subtle features. These limitations were reflected by larger mean differences, higher MAE and RMSE values, weaker correlations, and a reduced ability to discriminate finer-scale riparian characteristics compared with high-resolution imagery.

Table 19. Qualitative synthesis of the relative performance of field survey, high-resolution imagery (2.5 cm), and standard-resolution imagery (25 cm) across the evaluation criteria considered in this study

Evaluation criterion	Field survey	High-resolution imagery (2.5 cm)	Standard-resolution imagery (25 cm)
Information content	Very High	High	Moderate
Interpretation confidence	Very High	High	Moderate
Ability to differentiate riparian characteristics	High	High	Moderate
Detection of fine-scale characteristics	High	Moderate–High	Low
Repeatability and consistency	Moderate	High	High
Quality assurance capability	Moderate	High	High
Cost efficiency	Low	Low-Moderate	High
Operational flexibility	Moderate	High	High
Scalability	Low	Moderate	High
Suitability for repeat monitoring	Moderate	High	High
GIS integration and data management	Moderate	High	High
Future automation potential	Moderate	High	High

Notes: Ratings integrate the quantitative agreement analyses (section 5.2) with the practical implementation, operational, and technical assessments presented in sections 5.4.1–5.4.3.

The study also demonstrated that monitoring performance depended as much on the characteristic being assessed as on the monitoring method itself. Characteristics defined primarily by their spatial extent or structural attributes were consistently reproduced from aerial imagery, whereas characteristics requiring interpretation of functional condition, diffuse boundaries, recent disturbance, or subtle physical features exhibited greater variability and, in some cases, differences between methods. These differences reflected the respective strengths of field and aerial observations together with the influence of image resolution, acquisition conditions, and stream complexity on assessor confidence.

Overall, the three monitoring approaches should be viewed as complementary rather than competing methods. Field surveys maximise observational detail but require the greatest implementation effort. High-resolution imagery provides the best overall balance between information content, repeatability, implementation efficiency, and scalability, while standard-resolution imagery provides the lowest-cost and most scalable option for broad-scale monitoring where high-resolution imagery is unavailable or unnecessary. Consequently, the most appropriate monitoring approach depends on the objectives of the monitoring programme, the level of detail required, and the riparian characteristics being assessed, with high-resolution imagery providing the best overall balance between information content, repeatability, implementation effort, scalability, and future opportunities for automation.

6 Implications for national monitoring

6.1 Selecting the appropriate monitoring approach

Selection of the most appropriate monitoring approach should be guided primarily by the objectives of the monitoring programme rather than by the performance of any single method. Although field surveys provided the greatest amount of information, the agreement analyses demonstrated that several of the core streambank and riparian characteristics (including fencing extent, woody vegetation, riparian vegetation width, and stream shading) could be assessed consistently using aerial imagery. Consequently, the additional information obtained from field surveys will not necessarily improve the ability to evaluate overall riparian condition for every monitoring programme.

An equally important consideration is whether additional information provides meaningful value for the intended monitoring objective. Characteristics requiring interpretation of condition, including fencing effectiveness, stock pugging, streambank erosion, and channel obstructions, showed greater disagreement between methods and may therefore be more appropriately reserved for targeted field assessment. Monitoring programmes should prioritise characteristics that directly support reporting and management decisions rather than attempting to maximise the number of attributes collected. However, these additional characteristics may provide valuable co-benefits for compliance, ecological assessments, or site-specific management.

In our opinion, high-resolution imagery provided the best overall balance between information content, repeatability, implementation effort, and scalability. Stereo interpretation did not substantially alter estimates for most core monitoring characteristics but improved assessor confidence for fencing effectiveness, vegetation structure/height, streambank erosion type, and the presence and nature of channel obstructions. This additional perspective was particularly valuable where channels were deeply incised, riparian vegetation was structurally complex, or subtle changes in bank form were present. For routine regional monitoring, however, the additional specialist interpretation effort associated with stereo imagery is likely to be justified only where these characteristics are important to monitoring objectives.

Rather than viewing field surveys and imagery-based assessment as competing approaches, they are better considered as complementary methods. For many of the core streambank and riparian characteristics the three approaches produced comparable results, indicating that they can probably be used interchangeably for those attributes. Field surveys provide the greatest additional value where characteristics cannot be reliably interpreted from imagery or where direct verification is required, while imagery-based assessment provides a consistent, efficient, and repeatable means of assessing those characteristics that can be confidently derived from aerial imagery. Consequently, the choice of monitoring approach should be guided by the objectives of the monitoring programme, the information required to support management decisions, and the resources available for implementation.

6.2 Monitoring frameworks for different objectives

Different monitoring objectives warrant different combinations of field- and imagery-based assessment. For regional state of the environment (SOE) monitoring, desktop interpretation of high-resolution aerial imagery provides the most favourable balance between information quality, repeatability, operational efficiency, and scalability. The permanent, spatially referenced nature of imagery-derived data sets supports consistent interpretation, independent quality assurance, and straightforward integration with existing GIS-based monitoring systems, making this approach well suited to regional and national reporting.

The quantitative agreement analyses demonstrated that many of the core structural indicators used in regional reporting, including fencing extent, woody vegetation, riparian width, and stream shading, were reproduced consistently from high-resolution imagery. These characteristics therefore provide a strong basis for desktop monitoring frameworks. Conversely, indicators requiring assessment of functional condition or recent disturbance continued to benefit from targeted field verification.

Field surveys remain important where objectives focus on characteristics that depend on direct assessment of site condition. Characteristics such as livestock access, fence effectiveness, stock pugging, subtle erosion processes, and other indicators of streambank condition cannot always be interpreted reliably from aerial imagery and may therefore continue to require field verification.

A hybrid monitoring framework is therefore likely to provide the greatest overall benefit. Desktop interpretation should form the primary monitoring method for characteristics that can be measured consistently from imagery, while field surveys should be targeted towards locations or characteristics where additional information is required or where imagery cannot confidently resolve site conditions. Rather than undertaking complete reach surveys, many field visits could be limited to rapid verification of specific characteristics, either in person or through communication with landowners, substantially reducing time, implementation costs, and health and safety requirements while maintaining confidence in the final assessment. For a monitoring programme, field verification may only be required during establishment of the monitoring network or where conditions have changed substantially, as many of the core riparian characteristics are relatively stable through time. Subsequent monitoring could therefore rely primarily on desktop assessment, with targeted field visits undertaken only where validation or additional site-specific information is required.

It is also worth noting that field surveys provide opportunities to engage directly with landowners and gain context about site management that may not be evident from imagery alone, such as whether riparian areas are intentionally grazed. Our experience was that these interactions were overwhelmingly positive, providing a valuable opportunity to communicate research, discuss riparian management initiatives, and strengthen relationships between landowners and regional agencies. Although difficult to quantify, the value of these interactions should be recognised when considering the broader benefits of field-based monitoring programmes.

6.3 Future national monitoring

There is considerable opportunity to develop a more nationally consistent framework for monitoring streambank erosion and riparian condition. The methods compared in this study relied on standard GIS workflows, consistent interpretation rules, and spatially referenced data sets that can be readily integrated into existing regional monitoring systems. This provides a practical foundation for more consistent assessment and reporting across regional councils.

The results indicate that future national monitoring programmes would benefit from simplifying monitoring protocols to focus on characteristics that can be measured consistently, objectively, and repeatably across regions. Fencing extent, woody vegetation, riparian vegetation width, and overall stream shading all exhibited strong agreement between monitoring approaches and are well suited to imagery-based assessment. Conversely, characteristics requiring substantial assessor judgement or exhibiting consistent systematic differences between imagery and field surveys, including fencing effectiveness, vegetation structure and height, streambank erosion, presence and nature of channel obstructions, and pugging, are likely to remain better suited to targeted field assessment.

A logical next step would be to explore the development of a dedicated national desktop monitoring approach that integrates aerial imagery, complementary spatial data sets, automated feature extraction, and targeted field verification. Rather than adapting existing field-based protocols for desktop assessment, such a framework could be specifically designed around those characteristics that can be measured consistently, objectively, and efficiently using remotely-sensed data.

Future monitoring programmes are likely to benefit from increasing integration with nationally available spatial data sets, including LiDAR-derived terrain models, canopy height models, woody vegetation mapping, and other geospatial products. Together with advances in object-based image analysis, machine learning, and artificial intelligence, these data sets provide considerable opportunity to develop data-driven, semi-automated monitoring workflows. Recent work has already demonstrated the feasibility of applying deep learning to imagery to map riparian vegetation classes and assess planting success at regional scales, providing an example of how automated image interpretation can support future national monitoring programmes (Boon & Knox 2023). Such approaches have the potential to reduce subjective interpretation through the consistent application of classification rules, improve processing efficiency, and substantially increase the capacity to assess riparian condition across much larger spatial extents. This could also enable monitoring to move beyond discrete, site-based assessments towards more comprehensive evaluations of entire stream networks with region-wide imagery.

Rather than attempting to replicate detailed field observation, future national monitoring should capitalise on the complementary strengths of field- and imagery-based approaches. A purpose-built desktop monitoring approach that integrates aerial imagery, complementary spatial data sets, automated feature extraction, and targeted field verification (including landowner interaction) would maximise consistency, repeatability, efficiency, and scalability while retaining field assessments (and landowner–agency relationships) for characteristics that continue to require direct observation or validation. Such a framework represents a logical next step towards nationally consistent monitoring of streambank erosion and riparian condition.

7 Study limitations

7.1 Study design

This study represents an initial comparison of field-based and imagery-based approaches for monitoring streambank erosion and riparian condition in New Zealand. Although the study included 31 stream reaches spanning a broad range of stream sizes, riparian conditions, and pastoral and horticultural land uses, the findings should be interpreted within the scope of the study design.

The comparison was undertaken within a single region, and although the sites captured substantial variability in stream morphology and riparian condition, they may not represent the full range of stream environments encountered in New Zealand. Dairy-dominated systems, large lowland rivers, highly modified urban waterways, and densely forested catchments were not represented, and these are a key focus of riparian fencing initiatives. Consequently, additional evaluation across a wider range of regions, stream types, land uses, and environmental settings would improve confidence in the national applicability of the findings.

The relatively small number of monitoring sites also limited the statistical power of some comparisons. Although the sample size was sufficient to quantify overall agreement, estimate mean differences, and detect systematic differences for the principal monitoring characteristics, it limited more detailed assessment of method performance within individual land-use classes, stream types, or riparian conditions. Future studies incorporating larger and more geographically diverse site networks would enable more robust evaluation of how monitoring performance varies under different environmental conditions and would improve confidence in nationally applicable recommendations.

7.2 Method comparison

Several aspects of the study design influenced the comparison between monitoring approaches. Image acquisition and field surveys were not undertaken on the same dates, meaning that changes on the ground between survey dates contributed to some differences between measured stream bank and riparian characteristic measurements. Changes in land use, livestock presence, temporary fencing, vegetation management, seasonal vegetation growth, recent erosion, or flood damage all had the potential to alter site conditions independently of the monitoring approach. Consequently, some disagreement reflected genuine on-the-ground change rather than differences in assessment accuracy.

Field surveys were used as the best-estimate comparative benchmark because they provided direct observations of streambank and riparian condition. However, field observations should not be regarded as an absolute representation of riparian condition. Many characteristics evaluated in this study, including fencing extent, woody vegetation, riparian vegetation width, and overall stream shading, describe streambank erosion and riparian characteristics that may be estimated as consistently (or in some situations more consistently) from an aerial perspective where the entire riparian corridor is visible. Conversely, field surveys provide access to characteristics that cannot readily be assessed from imagery including fencing effectiveness, vegetation structure or height, streambank erosion, pugging, and the presence and nature of channel obstructions. Consequently, the comparison should be interpreted as an evaluation of agreement between monitoring approaches rather than a validation of one method against another.

The study also highlighted that several streambank and riparian characteristics are inherently subjective, irrespective of the monitoring approach. Defining channel edges, riparian boundaries, vegetation-width classes, complete versus incomplete stream shading, or the threshold for recording erosion required judgement and could reasonably differ between assessors. Similarly, complex channel morphology, multiple bank surfaces, dense riparian vegetation, and diffuse floodplain margins introduced uncertainty for both field and imagery-based assessments. Although every effort was made to standardise interpretation through detailed protocols and quality assurance, some degree of assessor variability is unavoidable.

Formal inter- and intra-observer repeatability testing was beyond the scope of this study. Instead, repeatability was inferred from the quantitative agreement analyses, including measures of mean difference, MAE, RMSE, correlation, and qualitative observations made during method development, implementation, and quality assurance. Independent reassessment of the same sites by multiple field and imagery assessors would provide a more robust assessment of observer repeatability and strengthen future evaluations.

7.3 Future evaluation

The imagery data sets evaluated in this study represent one implementation of high-resolution (2.5 cm) and standard-resolution (25 cm) aerial imagery rather than the full range of imagery products currently available. Image spatial and spectral resolution, acquisition season, sun angle, illumination, shadowing, vegetation phenology, and orthophoto processing all influence the visibility of streambank and riparian characteristics and therefore the confidence with which they can be interpreted.

Future evaluations would benefit from assessing a wider range of imagery products, acquisition conditions, and remote-sensing technologies, including LiDAR, canopy height and other vegetation structure models, and multi-temporal imagery. Similarly, advances in object-based image analysis, machine learning, and artificial intelligence provide opportunities to evaluate automated approaches against both field surveys and expert desktop interpretation. Attention should be given to determining which riparian characteristics can be measured consistently with low uncertainty and from remotely sensed data, and which measurements continue to require targeted field verification. Such studies would further refine monitoring protocols and improve confidence in the development of nationally consistent, imagery-based monitoring programmes.

8 Conclusions

This study compared field surveys, high-resolution aerial imagery, and standard-resolution aerial imagery for monitoring streambank erosion and riparian condition. The results demonstrated that monitoring performance depended primarily on the riparian characteristic being assessed rather than the monitoring method itself. Characteristics defined by their spatial extent or readily identifiable physical features, including fencing extent, woody vegetation, riparian vegetation width, and overall stream shading, were reproduced consistently from aerial imagery. High-resolution imagery showed particularly strong agreement with field surveys and estimates of key characteristics listed above.

In contrast, characteristics requiring assessment of condition or subtle physical features, including fence effectiveness, streambank erosion, stock pugging, and channel obstructions, proved more difficult to assess consistently from aerial imagery. Although, high-resolution imagery, in particular, generally identified the presence of these characteristics, it frequently underestimated their extent or required greater assessor interpretation, translating to lower confidence. Consequently, field surveys provide the greatest value for monitoring programmes that require detailed assessment of streambank condition and other fine-scale site characteristics.

High-resolution imagery provided the strongest overall balance between information, repeatability, implementation effort, and scalability. Although absolute implementation costs depended on staffing arrangements and imagery availability, the relative advantages of imagery-based monitoring over field surveys remained consistent across the implementation scenarios evaluated. It substantially reduced the logistical constraints associated with field surveys while producing spatially referenced data sets that supported more transparent interpretation, quality assurance, and future repeat monitoring. Stereo interpretation improved confidence in complex environments by providing additional three-dimensional information on streambank morphology, vegetation structure, and topographic context, although the benefits for many routine monitoring characteristics were relatively modest compared with the additional technical expertise required. Standard-resolution imagery remained valuable for broad-scale assessments where extensive spatial coverage or low implementation costs were priorities, particularly where suitable imagery was already available. However, compared with high-resolution imagery, it consistently provided less information for fine-scale interpretation and resulted in lower confidence in the assessments.

Emerging data-driven and semi-automated approaches provide opportunities for dedicated imagery-based monitoring approaches designed around the characteristics that can be measured consistently, objectively, and efficiently from aerial or remotely sensed data. Integrating aerial imagery with complementary spatial data sets, automated feature extraction, and machine-learning techniques has the potential to improve consistency, reduce subjective interpretation, and increase monitoring efficiency. Imagery can serve as the primary tool for assessing structural riparian characteristics, complemented by targeted field verification where direct observation remains necessary. Together, these complementary approaches have the potential to maximise repeatability, operational efficiency, scalability, and national consistency while retaining the strengths of field surveys for characteristics that cannot yet be reliably assessed from aerial imagery.

Ultimately, selecting the most appropriate monitoring approach requires balancing trade-offs between information requirements, implementation costs, staffing requirements, scalability, and available resources. This study provides an evidence base to inform those decisions by quantifying the strengths, limitations, and resource requirements of three complementary monitoring approaches. However, determining how these factors should be prioritised within a national monitoring or environmental limit-setting framework will depend on broader policy objectives and was beyond the scope of this study.

9 Recommendations

1. *Consider high-resolution aerial imagery as the primary monitoring approach.* High-resolution aerial imagery appears to provide the strongest overall balance between information content, repeatability, implementation effort, and scalability, making it well suited as the primary approach for regional SOE monitoring of structural riparian characteristics. However, targeted field surveys should complement imagery where direct observation is required for specific characteristics, or where dense canopy cover, riparian vegetation, or other channel obstructions reduce confidence in imagery-based assessment. The final choice of monitoring approach should balance information requirements, implementation costs, staffing requirements, scalability, and available resources, with the relative importance of these factors determined by the objectives of the monitoring and policy framework.
2. *Continue validation and refinement*. Future implementation should focus on simplifying monitoring protocols and definitions, prioritising characteristics that provide the greatest monitoring value, and evaluating emerging imagery products, acquisition strategies, and analytical methods as they become available. Continued validation across a wider range of regions, stream types, land uses, and environmental conditions will improve confidence in nationally consistent implementation and help ensure the monitoring method remains robust, efficient, and fit for purpose.

3 *Integrate complementary spatial data sets and emerging technologies*. Future research should look to integrate nationally available spatial data sets, including LiDAR-derived terrain models, canopy height models, woody vegetation mapping, and other geospatial products alongside aerial imagery. Object-based image analysis, machine learning, and artificial intelligence should be explored to support semi-automated assessment of structural riparian characteristics, improve consistency, reduce assessor subjectivity, and increase monitoring efficiency across large spatial extents.

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Declaration of the use of generative AI / AI-assisted technologies

This research work included the use of ChatGPT to edit code for data processing workflows and figure outputs, and to edit text. After using this tool/service, the content was reviewed and edited as needed by the authors.

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Appendix 1 – Field-based riparian survey characteristics

Field-based riparian survey characteristic forms based on Waikato Regional Council riparian monitoring programme (see Storey 2010; Jones et al. 2016; Norris et al. 2020, 2025).

1. General site characteristics

The general site characteristics form (Table A1.1) is to be filled in at the start point and rechecked at the end point to ensure any changes that need to be made are completed.

Table A1.1. General site characteristics (general form)

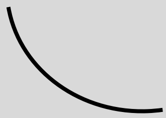
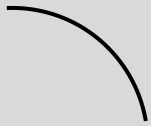
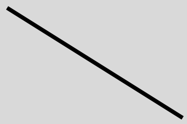
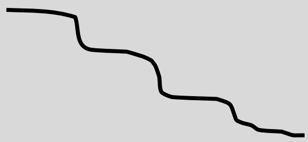
Characteristic	Variable	Description
Site ID		Enter the site reference number.
Site status	New	The site has not previously been surveyed.
	Continued	The site has been surveyed at least once before.
	Abandoned	The site cannot be surveyed. *[Note: record a comment as to the reason for it being abandoned (e.g. landowner declined access, unable to locate site, etc.)].*
Sampling date		Record the date the site was surveyed using the calendar.
Field observer		Select name from drop-down menu. *[Note: if 'Other' is selected, the name of the observer must be recorded in the 'Comments' form].*
Farm type *[Note: farm type identifies the predominant type of productive enterprise being undertaken on the land as opposed to the specific land use. For example, a large hill-country drystock farm may encompass a block of planted forest.]*	Drystock	Predominantly a beef, sheep, or other drystock farming enterprise. It includes dairy support (dairy cattle grazing).
	Dairy	Predominantly a dairy cattle farming enterprise where the milking shed is on the property (i.e. it is the milking platform).
	Forestry	Predominantly a forestry (planted forest) enterprise.
	Horticulture	Predominantly a horticultural enterprise including orchards, vineyards, etc
	Cropping	Predominantly a cropping enterprise (involving regular soil cultivation) including maize, vegetables, etc.
	Lifestyle	Predominantly a rural residential property or properties. May include a small orchard, small numbers of livestock, or some other niche productive use.
	Other	Predominantly some other farm type other than Drystock or Dairy.
Land use *[Note: record the predominant land use for the land immediately surrounding the entire sample site at the time of the survey].*	Beef	Predominantly beef cattle farming.
	Sheep	Predominantly sheep farming [*Note: record in the 'Comments' form if the sheep are milked.*]
	Sheep & beef	Predominantly both sheep and beef farming. [*Note: record in the 'Comments' form if the sheep are milked.*]
	Dairy support	Predominantly dairy cattle grazing.
	Deer	Predominantly deer farming.
	Goats	Predominantly goat farming [*Note: record in the 'Comments' form if the goats are milked.*]
	Horses	Predominantly horse breeding/training/grazing.
	Llamas/alpacas	Predominantly llama or alpaca farming.
	Pigs	Predominantly pig farming.

Characteristic	Variable	Description
	Dairy (platform)	Predominantly dairy cattle farming where the milking shed is on the property (i.e. the milking platform).
	Poultry	Predominantly domestic fowl (poultry) farming (e.g. hens, turkeys, ducks, and geese).
	Cropping	Predominantly cropping (i.e. signs of regular soil cultivation) of unknown type.
	Maize cropping	Predominantly maize cropping.
	Vege cropping	Predominantly vegetable cropping.
	Fodder cropping	Predominantly fodder (cattle feed) cropping.
	Horticulture	Predominantly horticultural uses such as orchards, vineyards, etc.
	Orchard	Predominantly an orchard.
	Vineyard	Predominantly a vineyard.
	Manuka honey	Predominantly mānuka planted for commercial honey production.
	Planted forest	Predominantly a planted forest such as a pine forest.
	Other	Predominantly any other land use not listed above. *[Note: if 'Other' is selected, the observed land use must be described in the 'Comments' form.]*
Break feeding *Is break-feeding of livestock occurring in the vicinity of the site? If so, record its type.* *[Note: to qualify as 'in the vicinity' the break-feeding must be occurring in the same general slope type – e.g. plains (0–3°), undulating/rolling land (4–15°), or steeper land (16° or more)].*	None	There is no break-feeding of livestock evident in the vicinity of the survey site.
	Grass	Livestock are being break-fed pasture in the vicinity of the survey site.
	Fodder crop	Livestock are being break-fed a fodder crop in the vicinity of the survey site.
	Other	Livestock are being break-fed in the vicinity of the survey site. *[Note: if 'Other' is selected, the observed feed type must be described in the 'Comments' form.]*
Accord stream *Does the waterway qualify as a Dairy Clean Streams Accord stream?* *[Note: Estimates of water depth are to be made visually from the riparian margin – do not enter the waterway].*	Yes	The land use is dairy farming (milking platform) and the waterway is wider than 1 m, more than ankle deep, and permanently flowing.
	No	The land use is not dairy farming or the waterway does not meet all of the criteria listed above.
Stream permanent *Is the waterway permanently flowing?*	Yes	The stream or drain appears to be permanently flowing (i.e. carries water throughout the year).
	No	The stream or drain appears to be ephemeral (i.e. carries water only during wet periods).
Weather *What are the current weather conditions?*	Fine	Blue skies, little to no cloud
	Overcast	Cloudy, little to no blue sky
	Rain	Persistent, steady rain for over 30 minutes
	Showers	Inconsistent periods of light rain no longer than 30 minutes at a time

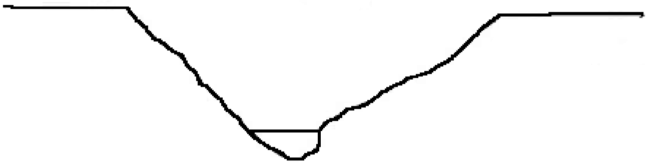
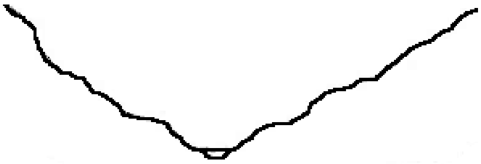
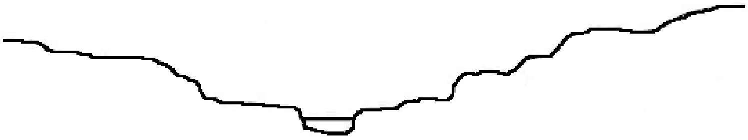
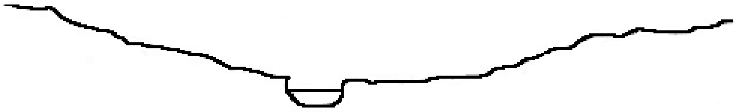
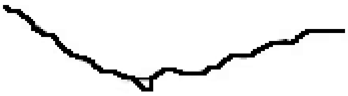
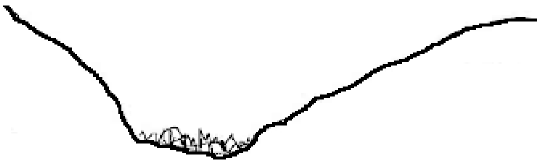
2. Point characteristics

The points data form (Table A1.2) is filled in at the start, middle, and end points at the site as close to the points as possible.

Table A1.2. Point characteristics (points form).

Characteristic	Variable	Description
Location	Start point	Locate the start point of the survey.
	Middle point	Locate the middle point of the survey.
	End point	Locate the end point of the survey.
Side	True right	The bank being described at the selected point is on the true right.
	True left	The bank being described at the selected point is on the true left.
Bank shape	Concave	
	Convex	
	Linear	
	Terraced	
Bank slope	Actual slope value recorded	Measure the slope of the streambank at three points (start, middle, and end) along the sample site length using a clinometer.
Bank height *[Note: estimate the distance between the streambed and the top of the bank.]*	<1 m	Bank height is less than 1 m.
	≥1–9 m	Bank height is between 1 and 9 m *[Note: select the estimated bank height value to the nearest metre from the drop-down menu.]*
	>9 m	Bank height is more than 9 m.
Channel width *[Note: average width is recorded].*	≤1 m	Less than or equal to 1 m.
	>1–2 m	Between greater than 1 and 2 m.
	>2–3 m	Between greater than 2 and 3 m.
	>3–5 m	Between greater than 3 and 5 m.
	>5–10 m	Between greater than 5 and 10 m.
	>10 m	Greater than 10 m.
Streambed type *Diameter size*	Silt	0.002 to 0.063 mm.
	Sand	>0.063 to 2.0 mm.
	Gravel	>2 to 64 mm.

Characteristic	Variable	Description
	Cobble	>64 to 256 mm.
	Boulders	>256 mm.
Stock access type	None	No evidence for livestock access to the waterway or riparian margin is observed.
	Past	Some evidence for livestock access to the waterway or riparian margin at some time in the past is observed (e.g. pugged soil, grazed/browsed vegetation, trampled/broken vegetation, animal tracks, and dung).
	Recent	Evidence for recent livestock access to the waterway or riparian margin is clearly observed (e.g. recently pugged soil, grazed/browsed vegetation, trampled/broken vegetation; fresh animal tracks, and dung).
	Current	Livestock are observed in the waterway or riparian margin at time of survey.
Valley width *Estimated width (in meters) of the immediate valley where water would drain into the stream*	≤20 m	Valley width is 20 m or less.
	>20–50 m	Valley width is greater than 20 m and up to 50 m.
	>50–100 m	Valley width is greater than 50 m and up to 100 m.
	>100–200 m	Valley width is greater than 100 m and up to 200 m.
	>200–500 m	Valley width is greater than 200 m and up to 500 m.
	>500 m	Valley width is greater than 500 m.
Sedimentation	None	No evidence of sediment deposition within the riparian margin
	≤1 m	Sediment deposition only within 1 m of the stream edge
	>1–2 m	Sediment deposition within 1–2 m of stream edge
	>2–3 m	Sediment deposition within 2–3 m of stream edge
	>3–5 m	Sediment deposition within 3–5 m of stream edge
	>5–10 m	Sediment deposition within 5–10 m of stream edge
	>10 m	Sediment deposition ≥ 10 m from stream edge
Aquatic vegetation	Present	Visible aquatic plants are visible in the stream water
	Absent	No aquatic plants are present

Characteristic	Variable	Representative channel cross-section
Channel type	Lower floodplain (LF)	
	Entrenched floodplain (EF)	
	V-shaped entrenched (VE)	
	Upper floodplain low relief (UFL)	
	Upper floodplain high relief (UFH)	
	V-shaped hill valley (VHV)	
	U-shaped hill valley (UHV)	
	Shallow, V-shaped rolling (SVR)	
	Vegetated drain (VD)	
	Headwater wetland (HW)	

3. Continuous characteristics

The riparian margin, for the purposes of assessment for the survey, is defined as the area of land running immediately adjacent to both banks of a waterway that extends to either (in order of precedence): a fenceline erected for the specific purpose of excluding livestock from the waterway; a marked change in vegetation cover; a marked change in slope steepness; or up to 10 m from the edge of the waterway. (The vegetation buffer width is recorded as ≤1 m if there is no buffer.)

For continuous data collection (Table A1.3), the left and right banks are observed concurrently (using separate forms) with a member of the team monitoring the banks for characteristics changes, while other team member records the changes. Any changes to the vegetation, erosion, channel obstruction, etc. characteristics are recorded on the appropriate form (i.e. either the true left or true right).

Note: Complete both the true right and true left forms at the start point, clicking 'OK' at the end of each form (i.e. each form will have a separate point at the same location, before proceeding with the survey). True left is the left-hand side of the waterway facing downstream; true right is the right-hand bank facing downstream. 'Downstream' refers to the direction in which the water is flowing (i.e. if you are looking downstream, you are looking at the water flowing *away* from you).

Table A1.3. Continuous characteristics (true right and true left forms)

Characteristic	Variable	Description
Land use *[Note: record the land use for the land immediately adjacent to the waterway at the time of the survey.]*	Beef	Beef cattle farming.
	Sheep	Sheep farming
	Sheep & beef	Both sheep and beef farming.
	Dairy support	Dairy cattle grazing.
	Deer	Deer farming.
	Goats	Goat farming
	Horses	Horse breeding/training/grazing.
	Llamas/alpacas	Llama or alpaca farming.
	Pigs	Pig farming.
	Dairy (platform)	Dairy cattle farming where the milking shed is on the property (i.e. the milking platform).
	Poultry	Domestic fowl (poultry) farming (e.g. hens, turkeys, ducks, and geese).
	Cropping	Cropping (i.e. signs of regular soil cultivation) of unknown type.
	Maize cropping	Maize cropping.
	Vege cropping	Vegetable cropping.
	Fodder cropping	Fodder (cattle feed) cropping.
	Horticulture	Horticultural uses such as orchards, vineyards, etc.
	Orchard	An orchard.
	Vineyard	A vineyard.
	Manuka honey	Mānuka planted for commercial honey production.
	Planted forest	A planted forest such as a pine forest.
	Other	Any other land use not listed above. *[Note: if 'Other' is selected, the observed land use must be described in the 'Comments' form.]*

Characteristic	Variable	Description
Fence type	No fence	There is no fence present.
	Electric	Fence present has at least one wire that is electrified.
	Wire	Fence present is predominantly of wire construction.
	Wood	Fence present is predominantly of wood construction.
	Deer	Fence present is designed for deer (mesh and >2 m in height).
	Mesh	Fence present is of mesh construction.
	Virtual	No visible fence but use of Halter (or similar) technology on cattle to stop access has been confirmed with farmer.
	Other	Fence present is of some other design, material, or construction.
Fence status *[Note: assess fence effectiveness in relation to the type of livestock on the property that the fence is intended to exclude from the waterway.]*	Effective, permanent	The fence is permanently in place, with large concrete or wooden posts. The fence is robust and will stop livestock movement.
	Ineffective, permanent	The fence is permanently in place, with large concrete or wooden posts. The fence is not robust and livestock will move through/across it.
	Effective, temporary	The fence is easily removed; posts may be waratahs, standards, or wooden stakes. The fence is robust and will stop livestock movement.
	Ineffective, temporary	The fence is easily removed; posts may be waratahs, standards, or wooden stakes. The fence is not robust and livestock will move through/across it.
Vegetation type	Woody native	Predominance of indigenous (native) trees/shrubs.
	Woody willow	Predominance of willow (deciduous exotic) species.
	Woody deciduous	Predominance of deciduous exotic (non-native) tree and shrub species other than willow.
	Woody evergreen	Predominance of evergreen exotic (non-native) tree and shrub species.
	Grass & weeds	Predominance of low (<1 m) exotic (non-native) pastoral grasses and/or herbaceous weed species.
	Woody mixed	Combination of native and exotic species throughout the margin.
	Flax/sedge/rush	Predominance of (mainly indigenous) flax, sedge, and rush species. These species will often occur in wet or damp areas.
Vegetation structure	Forest	Tall, dense vegetation, trees close together.
	Treeland	>3 m high, widely spaced trees with grasses in between.
	Scrub	Low stature (<3 m) vegetation, shrubs/scrub close together.
	Shrubland	Low stature (<3 m) vegetation, shrubs/scrub widely spaced with grasses in between.
	Grassland	Exotic pastoral grasses, including small, low-lying weeds <1 m in height.
	Wetland	Often characterised by the presence of flax, sedge, and rush species.
Vegetation management *[Note: describe whether the riparian margin is intentionally planted or not, and whether it is intentionally managed/grazed or not. 'Managed' refers to the spraying or cutting of*	Planted & managed	The riparian vegetation has been intentionally planted and is being managed.
	Planted & unmanaged	The riparian vegetation has been intentionally planted but is not being managed.
	Planted & grazed	The riparian vegetation has been intentionally planted but is periodically grazed.
	Unplanted & managed	The riparian vegetation has not been intentionally planted but is being managed.

Characteristic	Variable	Description
weeds, grass, or other unwanted species.]	Unplanted & unmanaged	The riparian vegetation has not been intentionally planted and is not being managed.
	Unplanted & grazed	The riparian vegetation has not been intentionally planted and is periodically grazed.
Vegetation buffer width *[Note: average width is recorded.]*	≤1 m	Less or equal to 1 m.
	>1–2 m	Between 1 and 2 m.
	>2–3 m	Between 2 and 3 m.
	>3–5 m	Between 3 and 5 m.
	>5–10 m	Between 5 and 10 m.
	>10 m	Greater than 10 m.
Stream shade	No shading	No riparian vegetation provides shade to the stream channel.
	Incomplete shading	Riparian vegetation provides shade to part of the stream channel, while portions remain exposed to direct sunlight.
	Complete shading	Riparian vegetation provides shade across the entire or nearly the entire stream channel.
Stock access	None	No evidence of livestock access to the waterway or riparian margin is observed.
	Past	Some evidence of livestock access to the waterway or riparian margin at some time in the past is observed (e.g. pugged soil, grazed/browsed vegetation, trampled/broken vegetation, animal tracks, and dung).
	Recent	Evidence of recent livestock access to the waterway or riparian margin is clearly observed (e.g. recently pugged soil, grazed/browsed vegetation, trampled/broken vegetation; fresh animal tracks, and dung).
	Current	Livestock are observed in the waterway or riparian margin at time of survey. *[Note: record the number of stock observed in the in waterway or riparian margin in the 'Observed Access' field.]*
Erosion class *[Note: an erosion feature must have a width of at least 1 m before it is recorded.]*	No erosion	No erosion present.
	Recent	Likely to add sediment to the waterway when in flood.
	Active	Adding sediment to the waterway at the present time.
	Bare soil >50%	Bare soil with no (or very few) plants immediately adjacent to the stream
	Unobserved	Unable to access or see the stream bank directly
Erosion type	Scour	Localised erosion along stream banks due to the erosive action of flowing water.
	Slip	Soil slips involve the failure of the topsoil, usually 1 to 2 m in depth, which suddenly moves down a hill, often acting as a liquid with lumps
	Slump	Large blocks of soil break away and collapse, often when the bank is already damaged. Often the result of undercutting.
Pugging	Pugging (>50%)	Soil trampled by livestock across more than 50% of the streambank area.
	Pugging (≤50%)	Soil trampled by livestock across less than or equal to 50% of the streambank area.
	No pugging	No pugging in the adjacent soils
Channel obstruction/ access type	Non-living debris	Dead wood, plastic, metal, fencing materials, etc. in the stream flow.
	Willow	Willows in the stream flow.

Characteristic	Variable	Description
[Note: an obstruction is an object that blocks 50% or more of the waterway. Remember to close-off the obstruction feature by creating another point and selecting the blank space at the top of the drop-down menu].	Other live vegetation	Living vegetation (other than willows) in the stream flow.
	Dam	Dam structures including small farm dams, concrete walls stopping flow, etc.
	Weir	A weir structure across the width of the waterway that alters the flow and level of the water.
	Side entry	Side entries are tributary streams, drains, or pipes that flow into the main stream course.
	Culvert (SBA)	A single-barrel arch (SBA) culvert that allows water to flow under a waterway crossing or other channel obstruction.
	Culvert (SBC)	A single-barrel circular (SBC) culvert that allows water to flow under a waterway crossing or other channel obstruction.
	Culvert (MBC)	A multi-barrel arch (MBC) culvert that allows water to flow under a waterway crossing or other channel obstruction. Could include low-water crossings (usually 'dry').
	Culvert (BOX)	A box (BOX) culvert that allows water to flow under a waterway crossing or other channel obstruction.
	Constructed ford	A constructed area of controlled and regular animal or vehicle crossings through the water (excluding any culverted structures such as low-water crossings). These crossings are normally 'wet' rather than 'dry' (c.f. a low-water crossing).
	Streambed ford	Area of regular animal or vehicle crossings through the water across the streambed.
	Bridge ≤10 m	A bridge 10 m or less in length (generally a single-span bridge).
	Bridge >10 m	A bridge greater than 10 m in length (generally a multiple-span bridge).
	No channel obstruction	No channel obstruction to the stream. Use this to turn channel obstructions off.
Channel obstruction/ access length	Length (m)	Measure and record the length of the channel obstruction. *[Note:* channel *obstruction length is measured parallel to the streambank.]*
Capture blank GPS point		*Register a blank 'track' point at the beginning, middle, and end of each meander (substantial change of direction) of the stream along the sample length.*

4. General comments and photographs

Note any other points of interest (e.g. 'crack willow causing many channel obstructions to stream flow' or 'many large carp observed in stream').

Table A1.4. General comments

Comments	Description
	Make any comments relating to the site and the data being collected in the free-form field provided in the Comments form. If a particular characteristic being described does not fit the predefined classes well, explain here how it differs.

Photographs are to be taken using your mobile phone at the start, middle, and end of the site, and of any significant features observed (e.g. accessways, channel obstructions, severe erosion), or if there is any doubt as to what a feature should be classed as.

Appendix 2 – Desktop-based imagery assessment riparian survey characteristics

Desktop-based imagery assessment riparian survey characteristic forms based on Hawke's Bay Regional Council riparian monitoring programme (see Ireland 2025).

1. General site information

Table A2.1. General site information analysis form

Characteristic	Field	Description
Site ID		Enter the site reference number.
Site status	New	The site has not previously been surveyed.
	Continued	The site has been surveyed at least once before.
	Abandoned	The site cannot be surveyed (record reason).
Sampling date		Record the date the site was surveyed.
Farm type *[Note: farm type identifies the predominant type of productive enterprise being undertaken on the land as opposed to the specific land use. For example, a large hill-country drystock farm may encompass a block of planted forest.*	Drystock	Predominantly beef, sheep, or other drystock farming enterprise.
	Dairy	Predominantly dairy cattle farming enterprise.
	Horticulture	Predominantly orchards, vineyards, etc.
	Cropping	Predominantly cropping enterprise.
	Lifestyle	Predominantly rural residential property.
	Other	Other farm type.
Land use* *[Note: record the predominant land use for the land immediately surrounding the entire sample site at the time of the survey.]*	Beef	Predominantly beef cattle farming.
	Sheep	Predominantly sheep farming.
	Sheep & beef	Predominantly both sheep and beef farming.
	Dairy support	Predominantly dairy grazing.
	Deer	Predominantly deer farming.
	Goats	Predominantly goat farming.
	Horses	Predominantly horse breeding/training/grazing.
	Llamas/alpacas	Predominantly llama or alpaca farming.
	Pigs	Predominantly pig farming.
	Dairy (platform)	Predominantly dairy farming where milking shed is on site.
	Poultry	Predominantly domestic fowl farming.
	Cropping	Predominantly cropping.
	Maize cropping	Predominantly maize cropping.
	Vege cropping	Predominantly vegetable cropping.
	Fodder cropping	Predominantly fodder cropping.
	Horticulture	Predominantly horticulture.
	Orchard	Predominantly orchard.
	Vineyard	Predominantly vineyard.
	Manuka honey	Predominantly mānuka honey production.
	Planted forest	Predominantly planted forest.
	Public park	Predominantly public park.

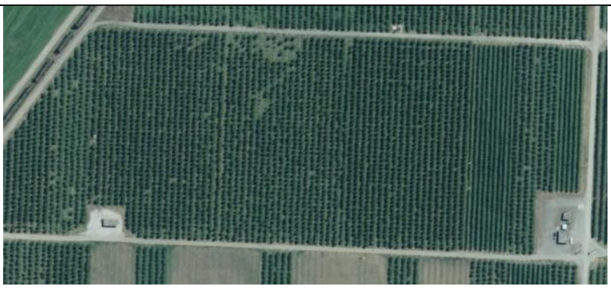
Characteristic	Field	Description
	Built-up area	Predominantly built-up area.
	Roading	Predominantly road network.
	Other	Other land use.
Break-feeding *Is break-feeding of livestock occurring in the vicinity of the site? If so, record its type.* *[Note: to qualify as 'in the vicinity' the break-feeding must be occurring in the same general slope type; e.g. plains (0–3°), undulating/rolling land (4–15°), or steeper land (16° or more)].*	None	No break-feeding evident.
	Grass	Break-feeding pasture.
	Fodder crop	Break-feeding fodder crop.
	Other	Other break-feeding type.
Accord stream *Does the waterway qualify as a Dairy Clean Streams Accord stream? [Note: estimates of water depth are to be made visually from the riparian margin – do not enter the waterway.]*	Yes	Dairy farming and meets stream criteria.
	No	Does not meet criteria.
Permanent flow *Is the waterway permanently flowing?*	Yes	Stream appears permanently flowing.
	No	Stream appears ephemeral.
Confidence level	High confidence	High confidence in assessment.
	Mid confidence	Medium confidence.
	Low confidence	Low confidence.

2. Continuous characteristics

Table A2.2. Key riparian characteristics observed along the waterway

Characteristic	Field	Description
Site ID and stream order *[Note: it is not always possible to identify stream orders in the field; the REC2 (River Environment Classification, version 2) layer could be used to assist with this information].*	Site ID	Enter the site reference number (from site info. layer).
	Stream order	Strahler numeric order based on number of tributaries; drains recorded as order 0.
Land use *(adjacent to waterway)* *[Note: record the land use for the land immediately adjacent to the waterway at the time of the survey.]*	Beef	Predominantly beef cattle farming.
	Sheep	Predominantly sheep farming.
	Sheep & beef	Predominantly both sheep and beef farming.
	Dairy support	Predominantly dairy cattle grazing.
	Deer	Predominantly deer farming.
	Goats	Predominantly goat farming.
	Horses	Predominantly horse breeding/training/grazing.
	Llamas/alpacas	Predominantly llama or alpaca farming.
	Pigs	Predominantly pig farming.
	Dairy (platform)	Predominantly dairy cattle farming where the milking shed is on the property.
	Poultry	Predominantly domestic fowl farming.
	Cropping	Predominantly cropping (regular soil cultivation). 
	Maize cropping	Predominantly maize cropping. 

Characteristic	Field	Description
	Vege cropping	Predominantly vegetable cropping.  
	Fodder cropping	Predominantly fodder (cattle feed) cropping. 
	Horticulture	Predominantly horticultural uses.
	Orchard	Predominantly an orchard. 

Characteristic	Field	Description
		
	Vineyard	Predominantly a vineyard. 
	Manuka honey	Predominantly mānuka planted for honey production.
	Planted forest	Predominantly planted forest. 
	Other	Other land use not listed above.
Fence type	No fence	There is no fence present.
	Electric	Fence present has at least one wire that is electrified.
	Wire	Fence present is predominantly of wire construction.
	Wood	Fence present is predominantly of wood construction.
	Deer	Fence present is designed for deer (mesh and >2 m in height).
	Mesh	Fence present is of mesh construction.
	Other	Fence present is of some other design, material, or construction.

Characteristic	Field	Description
Fence status *[Note: assess fence effectiveness in relation to the type of livestock on the property that the fence is intended to exclude from the waterway.]*	Effective, permanent	The fence is permanently in place, with large concrete or wooden posts. The fence is robust and will stop livestock movement.
	Ineffective, permanent	The fence is permanently in place, with large concrete or wooden posts. The fence is not robust and livestock will move through/across it.
	Effective, temporary	The fence is easily removed; posts may be waratahs, standards, or wooden stakes. The fence is robust and will stop livestock movement.
	Ineffective, temporary	The fence is easily removed; posts may be waratahs, standards, or wooden stakes. The fence is not robust and livestock will move through/across it.
Vegetation type	No vegetation	No presence of vegetation.
	Woody vegetation	For use in GIS desktop environment to record unknown type of vegetation.
	Woody native	Predominance of indigenous (native) trees/shrubs.
	Woody willow	Predominance of willow (deciduous exotic) species.
	Woody deciduous	Predominance of deciduous exotic (non-native) tree and shrub species other than willow.
	Woody evergreen	Predominance of evergreen exotic (non-native) tree and shrub species.
	Grass & weeds	Predominance of low (<1 m) exotic (non-native) pastoral grasses and/or herbaceous weed species.
	Flax/sedge/rush	Predominance of (mainly indigenous) flax, sedge, and rush species.
Vegetation structure	Forest	Tall, dense vegetation, trees close together.
	Treeland	>3 m high, widely spaced trees with grasses in between.
	Scrub	Low stature (<3 m) vegetation, shrubs/scrub close together.
	Shrubland	Low stature (<3 m), shrubs/scrub widely spaced with grasses in between.
	Grassland	Exotic pastoral grasses including small, low lying weeds <1 m in height.
	Wetland	Often characterised by the presence of flax, sedge, and rush species.
Vegetation buffer width *[Note: this is the width from the edge of the river or stream bank to the border of the riparian margin as defined earlier.]*	≤1 m	Less or equal to 1 m.
	>1–2 m	Between greater than 1 and 2 m.
	>2–3 m	Between greater than 2 and 3 m.
	>3–5 m	Between greater than 3 and 5 m.
	>5–10 m	Between greater than 5 and 10 m.
	>10 m	Greater than 10 m.
Vegetation management *[Note: describe whether the riparian margin is intentionally planted or not, and whether it is intentionally managed/grazed or not. 'Managed' refers to spraying or cutting of weeds, grass, or other unwanted species]*	Planted & managed	The riparian vegetation has been intentionally planted and is being managed.
	Planted & unmanaged	The riparian vegetation has been intentionally planted but is not being managed.
	Planted & grazed	The riparian vegetation has been intentionally planted but is periodically grazed.
	Unplanted & managed	The riparian vegetation has not been intentionally planted but is being managed.
	Unplanted & unmanaged	The riparian vegetation has not been intentionally planted and is not being managed.

Characteristic	Field	Description
	Unplanted & grazed	The riparian vegetation has not been intentionally planted and is periodically grazed.
Stock access type	None	No evidence of livestock access to the waterway or riparian margin is observed.
	Current	Livestock are observed in the waterway or riparian margin at time of survey.
	Past	Some evidence of livestock access at some time in the past is observed.
	Recent	Evidence of recent livestock access is clearly observed.
Erosion type *[Note: an erosion feature must have a width of at least 1 m before it is recorded.]*	No erosion	No erosion present.
	Recent	Likely to add sediment to the waterway when in flood.
	Active	Adding sediment to the waterway at the present time.
	Pugging (>50%)	Soil trampled by livestock across more than 50% of the streambank area. 
	Pugging (<50%)	Soil trampled by livestock across less than 50% of the streambank area. 
Channel obstruction/ access type *[Note: an channel obstruction is an object that blocks 50% or more of the waterway.]*	Non-living debris	Dead wood, plastic, metal, fencing materials, etc. in the stream flow.
	Willow	Willows in the stream flow.
	Other live vegetation	Living vegetation (other than willows) in the stream flow.
	Dam	Dam structures including small farm dams, concrete walls stopping flow.
	Weir	A structure across the width of the waterway that alters flow and level.
	Side entry	Tributary streams, drains, or pipes flowing into main stream.
	Culvert (SBA)	Single-barrel arch culvert.

Characteristic	Field	Description
	Culvert (SBC)	Single-barrel circular culvert.
	Culvert (MBC)	Multi-barrel culvert.
	Culvert (BOX)	Box culvert.
	Constructed ford	Controlled crossing area.
	Streambed ford	Regular crossing through streambed.
	Bridge ≤10 m	Bridge 10 m or less.
	Bridge >10 m	Bridge greater than 10 m.