Wildlife Connectivity Innovation

Requested by

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List of Abbreviations and Acronyms

AI	artificial intelligence
AIT	AI Image Toolkit
Caltrans	California Department of Transportation
Camtrap DP	Camera Trap Data Package
CDFW	California Department of Fish and Wildlife
CNN	convolutional neural networks
CT	camera trap
CTMS	Camera Trap Metadata Standard
GBIF	Global Biodiversity Information Facility
GIS	geographic information system
GS	gold standard
HITL	humans-in-the-loop
ML	machine learning
MLWIC	Machine Learning for Wildlife Image Classification
PSMFC	Pacific States Marine Fisheries Commission
QA	quality assurance
QC	quality control
RDBMS	relational database management system
SaaS	software as a service
TDWG	Biodiversity Information Standards
UWI	Urban Wildlife Institute
UWIN	Urban Wildlife Information Network
VES	visual encounter survey

Executive Summary

Background

The California Department of Transportation (Caltrans) is required to inventory and monitor wildlife barriers statewide. Research is needed to understand available technologies, including databases for tracking and sharing information, and the use of artificial intelligence (AI) for considerable reduction in staff time to evaluate and inventory thousands of photos. These technologies could efficiently and accurately process vast amounts of photographic data, aiding Caltrans in achieving a required goal while reducing time and labor costs.

Caltrans is seeking wildlife camera data management and AI solutions that will process images from camera traps, provide optimal data storage and data sharing capabilities, and reduce time and labor costs associated with manually processing large amounts of photographic data across 12 districts.

CTC & Associates surveyed selected experts with experience using photo recognition software and database software programs in a wildlife conservation context to gather information about their practical experience with these solutions. A literature search of relevant domestic and international research and related resources supplemented survey findings.

Summary of Findings

Survey of Practice

Two surveys of 17 experts who use photo recognition and database software programs to process and manage camera trap images sought information about the products and tools used by respondents. The surveys received eight responses across the two respondent groups:

- *Photo recognition software programs*. Of the 11 experts surveyed, three responded:
    - Assistant research scientist, University of Illinois Urbana-Champaign
    - Research ecologist, Western Transportation Institute (Montana State University)
    - Private sector photographer
- *Database software program*s. Of the six experts surveyed, five responded:
    - GIS coordinator, Caltrans
    - Senior environmental planner, Caltrans
    - Senior transportation engineer, Caltrans
    - GIS manager, Pacific States Marine Fisheries Commission
    - Applications software specialist, Pacific States Marine Fisheries Commission

Survey questions are provided in Appendix A.

A brief summary of survey findings begins on page 4 with Table ES1 and Table ES2, which provide highlights of the case studies appearing in the **Detailed Findings** section of this report (see page 12).

Table ES1. Case Study Highlights: Photo Recognition Software Programs

Primary Product or Tool	User Affiliation	Use Case	Workflow and Photo Volume	Assessment: Pros	Assessment: Cons
Wildlife Insights **(see NOTE below)**	University of Illinois Urbana-Champaign	Multiple objectives, including presence/absence, occupancy, abundance, distribution, behavior and evolution. Most software programs used by the respondent are geared toward specific objectives of a project rather than specific species or locations.	Wildlife Insights uses an online platform for uploads. The respondent uploads approximately 200,000 photos per project per season.	• Includes an intuitive interface. • Saves time with the AI feature by filtering out false triggers.	• Does not offer open access data. • Upload process can be difficult.
IrfanView	Western Transportation Institute (Montana State University)	Assess presence and relative abundance of wildlife species to support road ecology research.	Images are downloaded by project, location or date, with hundreds of thousands of images processed per year, likely totaling several million over time.	• Allows for lower memory use. • Permits the playing of image sequences like a movie. • Lacks screen flicker.	None noted.
Custom Model Combining YOLO and MegaDetector	Vishal Subramanyan Photography	Curate high-quality wildlife photos and videos for creative content production.	To use the custom-built model, the user opens the digital app and uploads a folder. The model then processes videos or thousands of photos in a single batch. Results are sorted automatically into new folders for easier organization.	• Is simple to use. • Supports video. • Sorts photos with animals automatically into a new folder. • Removes frames that don’t contain animals.	• Uploading takes a long time. • Runs slowly with large volumes.

NOTE: The University of Illinois Urbana-Champaign respondent recommended a path forward for Caltrans:

> For an organization the size of Caltrans, and the potential sensitivity of the data, the respondent recommends developing a custom AI tool and pairing it with Adobe Bridge. A custom-made AI tool could be created for a one-time investment of under $100,000, and it can be used for future projects.

Table ES2. Case Study Highlights: Database Software Programs

Primary Product or Tool	User Affiliation	Use Case	Features and Functions	Assessment: Pros	Assessment: Cons
Esri ArcCatalog*	Caltrans Division of Environmental Analysis	Create geodatabases in SQL and access them through ArcGIS tools such as dashboards and web maps.	• *Perform statistical analysis:* Yes, geoprocessing tools are available but the respondent has not used them. • *Permit simultaneous users:* No. • *Incorporate GIS:* Yes.	• Includes a simple user interface. • Is easy to use and connect with other databases.	Version control issues across Caltrans can be frustrating when new Esri features are announced but not usable until internal Caltrans systems are updated.
Microsoft SQL Server	Caltrans Division of Environmental Analysis	Track environmental data for delivery of transportation projects.	• *Perform statistical analysis:* No. • *Permit simultaneous users:* Yes. While the associated user interface allows for multiple users to log in with the same account, a single sign-on solution would be better. • *Incorporate GIS:* No.	• Provides a large amount of documentation and support. • Offers compatibility with other database types as linked servers. • Can be used with on-premises, cloud or container solutions. • Offers compatibility with spatial programs. • Has graphical user interface management tools that make managing databases simple.	None noted with regard to SQL Server. Caltrans' IT policies regarding administrative rights and the breakdown of roles and responsibilities make database management overly complicated. The respondent suggests that this will be the case with any solution, since Caltrans will always need to find a way to host applications internally.
Esri ArcGIS	Caltrans Headquarters	Consolidate Caltrans' statewide culvert database.	• *Perform statistical analysis:* No. • *Permit simultaneous users:* Yes, 250. • *Incorporate GIS:* Yes.	• Supports mobile use. • Permits querying of large datasets.	Lag time when working with very large datasets

Primary Product or Tool	User Affiliation	Use Case	Features and Functions	Assessment: Pros	Assessment: Cons
Esri ArcGIS-based systems	Pacific States Marine Fisheries Commission	Create business tables for stand-alone relational database management system (RDBMS) geographic information system (GIS) (visualization, analysis and web services publication) for ArcGIS-based systems.	• *Perform statistical analysis*: Yes, basic and geostatistical analysis. • *Permit simultaneous users*: Yes, for viewing and querying data. Other access depends on assigned level of permissions. • *Incorporate GIS*: Yes.	• Performs spatial analysis. • Provides web-based editing, including geometry. • Allows for ease of integrating content to feed web applications on the ArcGIS platform.	• Performance issues may arise when working with live joins and related tables. For this reason, the respondent tends to work with publication datasets that are updated programmatically. • Working with related data in an RDBMS is not performant.
Microsoft Access and Esri ArcGIS Online	Pacific States Marine Fisheries Commission	Organize stream habitat data, fish passage data and other restoration project data.	• *Perform statistical analysis:* Yes, available to some extent. • *Permit simultaneous users:* No. • *Incorporate GIS:* Yes.	• Microsoft Access: Offers easy querying and Excel exports. • ArcGIS Online: Includes cloud storage and supports integration with online web maps and applications.	None noted.

* ArcCatalog is in "mature support," and Esri recommends that those using it migrate to ArcGIS Pro.

Related Research and Resources

Findings from a literature search of publicly available research include a sampling of domestic and international publications that are organized into the following topic areas:

- **Wildlife Camera Data Management in California**. The citations in this section highlight research and other publications that describe current practices in California for managing camera data. Included is a 2023 presentation abstract describing California Department of Fish and Wildlife's partnership with Wildlife Insights "to increase the security of its photos and holistically manage photos so that information can be shared across regions and programs, and assessments of wildlife communities can be done at landscape scales using existing camera data." As Dr. Lindsey Rich noted at the time of her presentation, "[California Department of Fish and Wildlife] staff from across the state have uploaded over 32 million images from across 10,250 camera deployments to Wildlife Insights, and there will be many more to come as historical data and new projects transition to the platform" (see page 21 for the citation for this presentation).
- **Solution and Tools.** Publications and product websites describing solutions or tools used to store, manage, process and analyze camera trap data are organized into the five categories presented below. For each category, a table identifies each tool, its sourcing (domestic or international; commercial, open-source or free) and how it is hosted (cloud, local or both).
    - *Camera trap analysis and AI tools.* These tools process camera trap images to detect, classify or annotate wildlife and other objects. Many use AI or machine learning for automated detection, while others provide manual review and tagging capabilities; see Table ES3.

Table ES3. Camera Trap Analysis and AI Tools

Tool	Domestic or International	Commercial, Open-Source or Free	Hosting: Cloud, Local or Both
AIT - AI Image Toolkit	International	Open Source	Local
Animl	Domestic	Open Source	Local
Conservation AI	International	Free	Cloud
Pytorch-Wildlife and MegaDetector	Domestic	Open Source	Both
Timelapse	Domestic	Free	Local
YOLO (You Only Look Once)	International	Open Source	Both

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    - *Data management platforms, web platforms and collaborative networks*. These platforms store, organize and manage camera trap image datasets, often supporting collaboration between multiple users or organizations. Many integrate with AI tools for species detection and allow for long-term data storage and sharing; see Table ES4.

Table ES4. Data Management Platforms, Web Platforms and Collaborative Networks

Tool	Domestic or International	Commercial, Open-Source or Free	Hosting: Cloud, Local or Both
Agouti	International	Open Source	Cloud
Camelot	International	Free	Local
Trapper	International	Open Source	Local, but can be hosted on a server
Urban Wildlife Information Network	Domestic	Collaborative Network	Both
Wildlife Insights	International	Free for majority of users; tiered subscription model for some organizations	Cloud

- *Image and metadata organization tools*. These general-purpose tools are used to view, organize and manage large image collections. While not specific to wildlife monitoring, they can be used in camera trap workflows to manage image files and associated metadata; see Table ES5.

Table ES5. Image and Metadata Organization Tools

Tool	Domestic or International	Commercial, Open-Source or Free	Hosting: Cloud, Local or Both
Adobe Bridge	Domestic	Free (commercial download)	Local
IrfanView	International	Free for noncommercial use	Local

- *Interoperability, data standards and analytical workflows*. This category includes standards for structuring wildlife monitoring data and analytical tools — often in R — that process, manage and analyze camera trap datasets. Standards like Camtrap DP ensure data consistency and compatibility, while associated R packages provide functions for standardized analysis and reporting; see Table ES6.

Table ES6. Interoperability, Data Standards and Analytical Workflows

Tool	Domestic or International	Commercial, Open-Source or Free	Hosting: Cloud, Local or Both
CameraTrapDetectoR	Domestic	Open Source (R package)	Local (can process data from local or cloud sources)

Tool	Domestic or International	Commercial, Open-Source or Free	Hosting: Cloud, Local or Both
Camtrap DP	International	Open Standard	Format/standard usable in both environments
camtrapR	International	Open Source (R package)	Local (can interact with cloud-stored data)
MLWIC2	Domestic	Open Source (R package)	Local
Wildlife Tools	Domestic	Open Source (R package)	Local (can process data from local or cloud sources)

- *GIS and field data collection tools*. The Esri tools identified below support mapping, spatial analysis and field data collection. They are used to record and manage camera trap locations, integrate image data with GIS and conduct spatial analysis; see Table ES7.

Table ES7. GIS and Field Data Collection Tools (by Esri)

Tool	Domestic or International	Commercial, Open-Source or Free	Hosting: Cloud, Local or Both
ArcGIS	Domestic	Commercial	See below for specific ArcGIS products.
ArcGIS Online	Domestic	Commercial	Cloud
ArcCatalog (legacy; Esri recommends migration to ArcGIS Pro)	Domestic	Commercial	Local (can connect to cloud-hosted data or services)
ArcGIS Pro	Domestic	Commercial	Local (optional cloud integration via ArcGIS Online)
ArcGIS Field Maps	Domestic	Commercial	Cloud
ArcGIS Survey123	Domestic	Commercial	Cloud

- **Capabilities and Limitations of AI in Monitoring Wildlife.** The publicly available research highlighted in this topic area examines how AI is transforming wildlife monitoring through faster image processing, species and individual identification, and integration into camera trap workflows. Studies highlight the efficiency gains of AI tools and platform-based solutions, particularly for filtering empty images and detecting common species. However, they also emphasize challenges such as dataset, geographic and speciesist bias, reduced accuracy for rare or visually similar species, and the need for human oversight.

- **Emerging AI-Integrated Systems for Wildlife Monitoring.** The research cited in this section highlights advances in integrating AI directly into wildlife monitoring systems, paving the way for “smart” camera traps and fully automated monitoring networks. Innovations include on-device AI processing for adaptive, long-term autonomous operation, privacy protection and poacher detection, as well as large-scale solar-powered camera networks with real-time data transmission, remote system management and automated species identification.

Gaps in Findings

While the two surveys received responses from almost half of those surveyed, the limited pool of potential respondents (17) resulted in a small response set. Several of the eight respondents offered limited details of their experiences with photo recognition software and database software programs. One potential respondent was unavailable to participate at the time of survey distribution and offered alternatives to survey participation.

Next Steps

Moving forward, Caltrans could consider:

- Evaluating the PI and identifying opportunities to implement identified options, needed research and/or testing.
- Following up with the survey respondents describing or recommending a custom model as the most practical and economical solution to address Caltrans’ photo recognition needs.
- Soliciting feedback from other individuals known to have experience using photo recognition software programs.
- Reviewing tables ES3 through ES7 in the **Executive Summary** and the accompanying details in the **Related Research and Resources** section of this report to assess the utility of the various options and identify those that are appropriate for additional investigation.

Detailed Findings

Background

The California Department of Transportation (Caltrans) is required to inventory and monitor wildlife barriers statewide. Research is needed to understand available technologies, including databases for tracking and sharing information, and the use of artificial intelligence (AI) for considerable reduction in staff time to evaluate and inventory thousands of photos. These technologies could efficiently and accurately process vast amounts of photographic data, aiding Caltrans in achieving a required goal while reducing time and labor costs.

This Preliminary Investigation sought information and research on wildlife camera data management and AI that will:

- Automatically process images from camera traps, filtering out nonanimal photos, identifying species and efficiently extracting insight from large amounts of data.
- Provide information to help Caltrans select the best way to store and share large amounts of data and photos.
- Process images efficiently and reduce significant staff time and labor costs that would otherwise be required under the current manual processing of photographic data across 12 districts.

Information for this investigation was gathered through a survey of experts who use software to capture, process, manage and analyze camera trap images. Supplementing survey findings are the results of a literature search that examined domestic and international published and in-progress research and related resources that consider the capabilities and limitations of camera data management products and related technologies.

Survey of Practice

Separate online surveys were distributed to 17 potential respondents identified by the Caltrans project panel in two categories of wildlife camera data management:

- Photo recognition software program experts.
- Database software program experts.

The two surveys sought information about specific products and tools used by respondents that can inform Caltrans' evaluation of camera trap software and database solutions that might be appropriate for its needs.

The survey received eight responses across the two respondent groups:

- *Photo recognition software programs*. Of the 11 experts surveyed, three responded:
  - Assistant research scientist, University of Illinois
  - Research ecologist, Western Transportation Institute (Montana State University)
  - Private sector photographer
- *Database software program*s. Of the six experts surveyed, five responded:
  - GIS coordinator, Caltrans
  - Senior environmental planner, Caltrans

- Senior transportation engineer, Caltrans
- GIS manager, Pacific States Marine Fisheries Commission
- Applications software specialist, Pacific States Marine Fisheries Commission

Survey findings are summarized as brief case studies in two categories: photo recognition software programs and database software programs. The tools and solutions highlighted in the case studies are described more fully in the **Related Research and Resources** section of this report.

Survey questions are provided in Appendix A.

Case Studies: Photo Recognition Software Programs

Respondents from two universities and one private sector photographer described the photo recognition software they use to inventory and monitor wildlife in eight topic areas:

- Use case for photo recognition
- Software tools used
- Workflow and photo volume
- Ease of use
- Features and functions
- Quality assurance strategy
- Assessment (primary software tool)
- Additional comments or recommendations

Two of the three respondents reported no usage fees for the software they use. The University of Illinois respondent noted that "[s]ome software has fees, like Adobe products."

Not all case studies include all topic areas listed above.

Illinois Natural History Survey, University of Illinois

The University of Illinois research scientist responding to the survey described his use of Wildlife Insights, citing its intuitiveness and capacity for large uploads but noting that Adobe Bridge has fewer issues with uploads than Wildlife Insights. The respondent recommends development of custom AI tool for Caltrans.

Contact: Max Allen, Assistant Research Scientist, Wildlife Ecology, University of Illinois Urbana-Champaign, 707-267-3683, maxallen@illinois.edu.

Topic Area	Description
Use Case for Photo Recognition	Multiple objectives, including presence/absence, occupancy, abundance, distribution, behavior and evolution. Most software programs used by the respondent are geared toward specific objectives of a project rather than specific species or locations.
Software Tools Used	• Adobe Bridge (preferred, based on manual tagging) • Wildlife Insights (described below) • eMammal

Topic Area	Description
Workflow and Photo Volume	Wildlife Insights uses an online platform for uploads. The respondent uploads approximately 200,000 photos per project per season.
Ease of Use	Wildlife Insights is intuitive to use but often runs into problems during uploading, while Adobe Bridge never has problems with uploads.
Features and Functions	• *Perform statistical analysis:* Yes, supports basic statistical analysis. • *Permit simultaneous users:* Yes, hundreds of users can access a given project with their own accounts.
Quality Assurance Strategy	While Wildlife Insights offers automated species identification with approximately 90% accuracy, the respondent recommends expert review of all images to ensure accuracy. For known species, accuracy can improve to about 96%. The respondent notes that accuracy has improved over time, demonstrating learning.
Assessment (Wildlife Insights)	**Pros:** • Includes an intuitive interface. • Saves time with the AI feature by filtering out false triggers. **Cons:** • Does not offer open access data. • Upload process can be difficult.
Additional Comments or Recommendations	For an organization the size of Caltrans, and the potential sensitivity of the data, the respondent recommends developing a custom AI tool and pairing it with Adobe Bridge. A custom-made AI tool could be created for a one-time investment of under $100,000, and it can be used for future projects.

Western Transportation Institute (Montana State University)

The university researcher responding to the survey manually reviews all images, detecting animals of all sizes with the eye. The respondent doesn't have enough confidence yet in AI to rely on it for reducing false triggers.

Contact: Marcel Huijser, Research Ecologist, 406-543-2377, mhuijser@montana.edu.

Topic Area	Description
Use Case for Photo Recognition	Assess presence and relative abundance of wildlife species to support road ecology research.
Software Tools Used	• IrfanView (for image viewing) • Timelapse2 (for data entry)
Workflow and Photo Volume	Images are downloaded by project, location or date, with hundreds of thousands of images processed per year, likely totaling several million over time.
Features and Functions	• *Perform statistical analysis:* No. • *Permit simultaneous users:* No.

Topic Area	Description
Quality Assurance Strategy	All images are manually reviewed rather than relying on software classification. While no software is used to filter out images of animals or identify them, great lengths are taken to reduce false triggers by vehicles and vegetation. The respondent expresses high confidence in his manual review approach and ability to detect animals with the eye, including small and fast-moving species like bats, mice and even insects. He notes that AI-based tools would require manual calibration and acceptance of a certain number of errors.
Assessment (IrfanView)	**Pros:** • Allows for lower memory use. • Permits the playing of image sequences like a movie. • Lacks screen flicker. **Cons:** None noted.
Additional Comments or Recommendations	Avoidance and reduction of false positives is the first step to reduce labor costs. AI can help avoid or reduce false positives, but the respondent doesn't have enough confidence in it yet and does not want his research to shift toward evaluating AI performance at the expense of answering road ecology questions.

Vishal Subramanyan Photography

The wildlife photographer who responded to the survey is also a team member of the California Wolf Project within University of California Berkeley's Rausser College of Natural Resources. He reported on his use of a custom software model developed by a friend. In alignment with his creative content production goals, the model only identifies whether an animal is in the frame.

Contact: Vishal Subramanyan, Wildlife Photographer, 510-292-1714, vishals@berkeley.edu.

Topic Area	Description
Use Case for Photo Recognition	Curate high-quality wildlife photos and videos for creative content production.
Software Tools Used	• Custom model combining YOLO and MegaDetector (preferred) • Limited experience with Wildlife Insights
Workflow and Photo Volume	To use the custom-built model, the user opens the digital app and uploads a folder. The model then processes videos or thousands of photos in a single batch. Results are sorted automatically into new folders for easier organization.
Ease of Use	The custom model is very straightforward and simple to use, and the user can select the confidence threshold.
Features and Functions	• *Perform statistical analysis:* No. • *Permit simultaneous users:* Not known.

Topic Area	Description
Quality Assurance Strategy	Because the goal is not species-level classification but rather getting good photos and videos where an animal is in the frame, the respondent sets a high confidence threshold, which works well for his purposes. The custom model cannot identify species — it only identifies whether an animal is in the frame. The model has been consistently trained, reducing the need for manual quality assurance/quality control (QA/QC) over time.
Assessment (Custom)	**Pros:** • Is simple to use. • Supports video. • Sorts photos with animals automatically into a new folder. • Removes frames that don't contain animals. **Cons:** • Uploading takes a long time. • Runs slowly with large volumes.

Case Studies: Database Software Programs

Three Caltrans respondents and two respondents from the Pacific States Marine Fisheries Commission (PSMFC) described the database software programs they use for long-term storage of photographic data and information sharing in seven topic areas:

- Use case for database
- Software tools used
- Workflow and ease of use
- Features and functions
- Quality assurance strategy
- Assessment (primary software tool)
- Additional comments or recommendations

Not all case studies include all topic areas listed above.

Caltrans Division of Environmental Analysis

This Caltrans respondent with geographic information system (GIS) expertise cited Esri's ArcCatalog and Microsoft SQL Server as his preferred software. Note that ArcCatalog is in "mature support," and Esri recommends those using it migrate to ArcGIS Pro.

Contact: Anthony Barnes, GIS Coordinator, 916-995-4597, anthony.barnes@dot.ca.gov.

Topic Area	Description
Use Case for Database	Create geodatabases in SQL and access them through ArcGIS tools such as dashboards and web maps.
Software Tools Used	• Esri ArcCatalog and Microsoft SQL Server (preferred) • Microsoft Access (used less frequently)

Topic Area	Description
Workflow and Ease of Use	It is moderately difficult to manage databases through ArcCatalog and fairly complex to utilize SQL Server.
Features and Functions	• *Perform statistical analysis:* Yes, geoprocessing tools are available but the respondent has not used them. • *Permit simultaneous users:* No. • *Incorporate GIS:* Yes.
Quality Assurance Strategy	In general, data experts QA the data. For externally published datasets, the respondent ensures the metadata is completed and geometries are correctly mapped. Additional QA depends on the type of data, such as DIST field, county acronyms and proper domains.
Assessment (Esri ArcCatalog)	**Pros:** • Includes a simple user interface. • Is easy to use and connect with other databases. **Cons:** • Version control issues across Caltrans can be frustrating when new Esri features are announced but not usable until internal Caltrans systems are updated.

Caltrans Division of Environmental Analysis

This senior environmental planner noted that while he prefers Microsoft SQL Server, complicated IT policies at Caltrans may preclude a solution that is not hosted internally.

Contact: Stefan Sutton, Project Manager, Senior Environmental Planner, 916-955-1592, stefan.sutton@dot.ca.gov.

Topic Area	Description
Use Case for Database	Track environmental data for delivery of transportation projects.
Software Tools Used	• Microsoft SQL Server (preferred) • Claris FileMaker • IBM DB2
Workflow and Ease of Use	As a management tool, Microsoft's SQL Management Studio is very powerful and flexible. (Azure Data Studio is a comparable tool for cloud solutions.) However, Caltrans' IT policies regarding administrative rights and the breakdown of roles and responsibilities make database management overly complicated. The respondent suggests that this will be the case with any solution, since Caltrans will always need to find a way to host applications internally.
Features and Functions	• *Perform statistical analysis:* No. • *Permit simultaneous users:* Yes. While the associated user interface allows for multiple users to log in with the same account, a single sign-on solution would be better. • *Incorporate GIS:* No.

Topic Area	Description
Quality Assurance Strategy	Data is entered by subject matter experts, and several data quality practices are in place to capture or eliminate data entry errors. The most significant quality issue is with user compliance, such as staff neglecting to enter data required for their projects.
Assessment (Microsoft SQL Server)	**Pros:** • Provides a large amount of documentation and support. • Offers compatibility with other database types as linked servers. • Can be used with on-premises, cloud or container solutions. • Offers compatibility with spatial programs. • Has graphical user interface management tools that make managing databases simple. **Cons:** None noted.

Caltrans Headquarters

This senior transportation engineer prefers Esri ArcGIS for its ability to query large datasets and uses Esri Field Maps and Survey123 for automated QA.

Contact: Jimmy Duong, Senior Transportation Engineer, 916-531-9978, Jimmy.Duong@dot.ca.gov.

Topic Area	Description
Use Case for Database	Consolidate Caltrans' statewide culvert database.

Software Tools Used	• Esri ArcGIS (preferred and primary platform)
	  ○ ArcGIS Field Maps
	  ○ ArcGIS Survey123
	• Microsoft SQL Server

Workflow and Ease of Use	Level of difficulty rated as "medium."
Features and Functions	• *Perform statistical analysis:* No. • *Permit simultaneous users:* Yes, 250. • *Incorporate GIS:* Yes.
Quality Assurance Strategy	QA/QC is automated in Survey123 and Field Maps.
Assessment (Esri ArcGIS)	**Pros:** • Supports mobile use. • Permits querying of large datasets. **Cons:** • Lag time when working with very large datasets.
Additional Comments or Recommendations	Organizations need to be able to do this work in-house or hire consultants in perpetuity.

Pacific States Marine Fisheries Commission

The first PSMFC respondent does not have much experience specific to photographic data and the use of AI but rather uses database software to create business tables for ArcGIS-based systems, which he prefers for GIS functionality, scalability and integration with the ArcGIS platform.

Contact: Van C. Hare, GIS Manager, 503-595-3155, vhare@psmfc.org.

Topic Area	Description
Use Case for Database	Create business tables for stand-alone relational database management system (RDBMS) GIS (visualization, analysis and web services publication) for ArcGIS-based systems.
Software Tools Used	• Microsoft SQL Server • PostgreSQL/ArcGIS Data Store • Oracle MySQL • ArcGIS File Geodatabase The respondent prefers ArcGIS-based systems for GIS functionality, scalability and ease of integration with the ArcGIS platform. For managing business tables, SQL Server is easy to use and provides established workflows. For multi-user and web-based editing contexts, the respondent prefers the ArcGIS Geodatabase on SQL Server and ArcGIS Data Store (PostgreSQL). File-based geodatabases are used and appreciated for performance and publishing purposes.
Workflow and Ease of Use (Esri ArcGIS geodatabase/data store software)	While there is an initial learning curve, the platform is well documented, includes access to quality training materials and is considerably more approachable than Oracle.
Features and Functions	• *Perform statistical analysis*: Yes, basic and geostatistical analysis. • *Permit simultaneous users*: Yes, for viewing and querying data. Other access depends on assigned level of permissions. • *Incorporate GIS*: Yes.
Quality Assurance Strategy	The QA process focuses primarily on spatial components and core attributes related to the location/feature, including value-added spatial referencing attributes.
Assessment (Esri ArcGIS-based systems)	**Pros:** • Performs spatial analysis. • Provides web-based editing, including geometry. • Allows for ease of integrating content to feed web applications on the ArcGIS platform. **Cons:** • Performance issues may arise when working with live joins and related tables. For this reason, the respondent tends to work with publication datasets that are updated programmatically. • Working with related data in an RDBMS is not performant.

Pacific States Marine Fisheries Commission

The second PSMFC respondent does not use large-scale database systems and prefers Microsoft Access for small-scale projects. However, she does use ArcGIS Online for cloud-based mapping applications and finds both tools easy to use.

Contact: Karen Wilson, Applications Software Specialist, 707-601-8557, karen.wilson@wildlife.ca.gov.

Topic Area	Description
Use Case for Database	Organize stream habitat data, fish passage data and other restoration project data.
Software Tools Used	• Microsoft Access preferred for small-scale project data • ESRI ArcGIS Online for data used for cloud-based online mapping applications
Workflow and Ease of Use	Both tools are easy to use.
Features and Functions	• *Perform statistical analysis:* Yes, available to some extent. • *Permit simultaneous users:* No. • *Incorporate GIS:* Yes.
Quality Assurance Strategy	Most QA is already complete when the respondent receives data. Photo file naming is standardized. Some data comes in via Esri ArcGIS Survey123, and the data entry forms use lookup tables and data types to help improve data quality.
Assessment (Microsoft Access and Esri ArcGIS Online)	**Pros:** • Microsoft Access: Offers easy querying and Excel exports. • Esri ArcGIS Online: Includes cloud storage and supports integration with online web maps and applications. **Cons:** • None noted.

Related Research and Resources

The related research and resources cited below are organized into these topic areas:

- Wildlife camera data management in California.
- Solutions and tools.
  - Camera trap analysis and AI tools.
  - Data management platforms, web platforms and collaborative networks.
  - Image and metadata organization tools.
  - Interoperability, data standards and analytical workflows.
  - GIS and field data collection tools.
- Capabilities and limitations of AI in monitoring wildlife.
- Emerging AI-integrated systems for wildlife monitoring.

Resources may be further categorized as domestic or international.

Wildlife Camera Data Management in California

The citations in this section highlight research and other publications that describe current practices in California for the use of photo recognition software.

Traditional Camera Traps, Lindsey Rich, 2025.
https://storymaps.arcgis.com/stories/4ec5555440bb45afa976545bba76c7d0
This storymap developed by California Department of Fish and Wildlife's Lindsey Rich addresses a range of topics associated with camera traps, including equipment, pre-field preparation, field deployment and equipment retrieval.

"Camera Trap Method Effectively Identifies Small Mammal Species in Forested Habitats," Barbara Clucas and Sydney L. McCluskey, *California Fish and Wildlife Journal*, Vol. 111, Issue 8, 2025.
https://journal.wildlife.ca.gov/2025/05/20/camera-trap-method-effectively-identifies-small-mammal-species-in-forested-habitats/
From the abstract: Effective survey methods to detect small mammal species are often needed to develop conservation and management plans in forested ecosystems. The ability to use non-invasive methods to identify small mammal species in the field is particularly useful as live trapping can be time consuming and potentially harmful to the study species. We tested a camera trap method in a coastal redwood (*Sequoia sempervirens*) forest for small mammals, originally designed by Gracanin et al. (2019) and called the "selfie trap," that uses a camera trap with a modified lens in a baited PVC tube. We determined if we could use this camera trap set-up on the ground to accurately identify small mammals to species to assess species diversity in a forested ecosystem as well as if it could withstand disturbance from larger mammals (e.g., bears). We surveyed for small mammals in areas of old-growth and second-growth coastal redwood forests in northwestern California. We detected 10 small mammal species and were able to identify most individuals to species including squirrel, chipmunk, mice, woodrat, shrew, vole and mole species. This camera trap set up also detected approximately 77% of small mammal species known to potentially occur in the area. Moreover, although larger mammals could interact with the camera trap set up, their disturbance was limited to when they were interacting with the trap, and the bait and camera set-up remained functional for subsequent small mammal detections. Thus, this method could be used instead of live trapping in complex forested ecosystems to effectively determine small mammal species presence, diversity and activity levels, avoiding disturbance from large mammals.

"Use of AI for Processing Camera Trap Images: California Fish and Wildlife's Partnership with Wildlife Insights for Storing, Processing and Sharing Camera Images," Lindsey Rich, California Department of Fish and Wildlife, *The Western Section of The Wildlife Society 2023 Annual Meeting,* February 2023. Presentation abstract at https://user.tws-west.org/abstracts/abstract_detail.php?abstractID=3184&k=Abf1fNBEZA8rg

From the presentation abstract: The California Department of Fish and Wildlife (CDFW) deploys thousands of cameras at strategic locations throughout the state to estimate wildlife distributions and population demographics, which is a critical step in detecting declines, managing populations and understanding ecosystem health. The thousands of cameras produce tens of millions of images, which present data storage, processing and sharing challenges. To address these challenges, CDFW partnered with Wildlife Insights, an online platform for storing, identifying and analyzing camera trap data. Wildlife Insights has enabled CDFW to increase the security of its photos and holistically manage photos so that information can be shared across regions and programs, and assessments of wildlife communities can be done at landscape scales using existing camera data. Further, Wildlife Insights' computer vision model expedites the processing of photos by automatically identifying blank images (e.g., images of moving vegetation), vehicles and species, which users can then review and manually verify. CDFW staff from across the state have uploaded over 32 million images from across 10,250 camera deployments to Wildlife Insights, and there will be many more to come as historical data and new projects transition to the platform.

"Use of AI for Processing Camera Trap Images: Using Machine Learning to Manage Large Remote Camera Datasets and Detect San Joaquin Fox in Western Merced County," Ryan B. Avery, Development Seed, *The Western Section of The Wildlife Society 2023 Annual Meeting,* February 2023. Presentation abstract at https://user.tws-west.org/abstracts/abstract_detail.php?abstractID=3112&k=XT59zAnWITUeU

From the presentation abstract: As a requirement of the Habitat Conservation Plan prepared for the Wright Solar Park project, ICF [International] has used 10 remote cameras annually since 2020 to determine if San Joaquin kit fox (*Vulpes macrotis mutica*) are present. Unbaited camera stations were established along the fence line of the solar facility and continuously collected images for [four] months in 2020 (May-August) and for [seven] months in 2021 and 2022 (February-August). Tens of thousands of images were collected each year. Traditionally, these large image collections are reviewed by humans, who need to sift through many uninteresting images. To improve this process, we created a data processing pipeline using Microsoft's open-source Megadetector and Species Classification machine learning models, developed from millions of examples of camera trap images. At the project site, we were able to filter out most images without objects of interest, leaving a manageable number of images for human review. The results of the surveys have confirmed the presence of San Joaquin kit fox at the site each year. There were [five] detections in 2020, [nine] detections in 2021 and 19 detections in 2022. We present methods for calibrating and running these models on large image collections typical of long-term monitoring projects.

"Comparing Camera Traps and Visual Encounter Surveys for Monitoring Small Animals," Madison K. Boynton, Matthew Toenies, Nicole Cornelius and Lindsey N. Rich, *California Fish and Wildlife Journal*, Vol. 107, Issue 2, pages 99-117, 2021.
https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=193716

From the abstract: Amphibian and reptile species face numerous threats including disease, habitat loss and degradation, invasive species, and global climate change. However, effective management and conservation of herpetofauna largely depends upon resource-intensive survey methodologies. Recent research has shown promise in the use of camera trapping techniques, but these methods must be tested alongside traditional methods to fully understand their advantages and disadvantages. To meet this research need, we tested two herpetofauna survey methods: a modified version of the Adapted-Hunt Drift Fence Technique, which combines a drift fence with camera traps; and a traditional method of visual encounter surveys (VES) with cover boards. Between June and August 2020, we conducted two VES and installed one drift fence with camera traps at ten sites in Monterey County, CA, USA. The drift fence/camera setup outperformed the VES in terms of number of observations and herpetofauna species detected. Drift fences with cameras produced a mean of 248 images of three to six species per site, while VES and cover objects produced a mean of 0.6 observations of zero to one species per site. Across all sites, we detected seven reptile and one amphibian species with the drift fence/camera setup, while VES resulted in identifications of two reptile and one amphibian species. In addition, drift fence/camera setups recorded a minimum of nine non-herpetofauna species including small mammals, birds and invertebrates. Our research supports that drift fences combined with camera traps offer an effective alternative to VES for large-scale, multi-species herpetofauna survey efforts. Furthermore, we suggest specific improvements to enhance this method's performance, cost-effectiveness and utility in remote environments. These advances in survey methods hold great promise for aiding efforts to manage and conserve global herpetofauna diversity.

Solutions and Tools

Publications and product websites describing solutions or tools used to store, manage, process and analyze camera trap data are organized into five categories:

- Camera trap analysis and AI tools.
- Data management platforms, web platforms and collaborative networks.
- Image and metadata organization tools.
- Interoperability, data standards and analytical workflows.
- GIS and field data collection tools.

NOTE: Many of the software and database solutions highlighted below are also described in tables ES3 through ES7 in the **Executive Summary** of this report.

Camera Trap Analysis and AI Tools

These tools process camera trap images to detect, classify or annotate wildlife and other objects. Many use AI or machine learning for automated detection, while others provide manual review and tagging capabilities.

AIT – AI Image Toolkit: Wildlife Monitoring and Camera Trap Data Management, Dudek, 2023.
https://ait.dudek.com/
From the website: The AI Image Toolkit, or AIT, is designed to manage camera trap projects including the processing of all camera trap images collected in the field. Biologists can "tag" the observation records with various attributes found in the image, such as the species, gender, age class, behavior and more. Various data exports and reports are available to summarize animal presence and activity at a location. This tool uses Microsoft's MegaDetector v5, an artificial neural network which has been trained to identify animals within images. When images come in from the field, they are processed by this library and those images which do not contain an animal are discarded.

This tool makes it easy to export data from individual sites. Additional exports will be made available by species and other attributes which will span locations and projects.

This tool provides a tagging style editing ability across projects based on the user's roles assigned. Users with the "data manager" role can create projects and locations and overall structure of the project while "taggers" can add observations (upload images) and update their attributes once they have been run through MegaDetector.

Related Resource:

> **"Use of AI for Processing Camera Trap Images: Artificial Intelligence-Supported Animal Image Processing,"** David P. Waetjen and Fraser Shilling, Road Ecology Center, UC Davis, *The Western Section of The Wildlife Society 2023 Annual Meeting,* February 2023.
> Presentation abstract at https://user.tws-west.org/abstracts/abstract_detail.php?abstractID=3181&k=dhPExvwRpqqkx
> *From the presentation abstract*: Artificial intelligence (AI) and machine learning are terms describing software approaches that can be trained to perform tasks. Pattern recognition is at the core of most AI tools, including the growing suite of approaches for identifying wildlife. We describe the AI Image Toolkit (AIT, https://ait.dudek.com), a web-based system using a series of tasks in an overall workflow: 1) processing of large image datasets to identify and isolate images containing animals, 2) management of image files as part of camera trap projects, and 3) provision of data useful in occupancy and other modeling. In the first case, raw data from camera traps are uploaded to a cloud location. The tool identifies images containing animals (>95% accuracy) and returns them to a user in a zip file, along with a count of number of individual animals. In the second case, images containing animals are transferred to a web-based system, where the user can tag images with species, number of animals, behavior, demographics and other information. In (3), data and metadata are organized and can be queried and automatically packaged into formats used in GIS or statistical analysis; for example, occupancy models, diversity indices, effectiveness of crossing structures.

Animl, The Nature Conservancy, 2025.
https://animl.camera/
The Animl website provides:

- Intro to AI for processing camera trap data
- How AI works in Animl
- Structure, concepts and terminology

From the website: Animl is an open-source platform for managing camera trap data, built by The Nature Conservancy. Animl was designed to:

- Accept camera trap data from a wide variety of camera trap types, integrate real-time data streams from wireless camera traps (VHF radio-based cameras, cellular cameras) or upload images in bulk from traditional, SD-card cameras
- Allow for the rapid deployment and integration of multiple machine learning models that may be suited for different environments, different target species, or different business use cases
- Empower users to configure custom machine learning pipelines to automatically predict what's in their images — and weed out empty images if nothing is detected
- Send automated alerts if a species of concern is detected
- Allow users to query, filter and sort images, review and validate ML [machine learning]-predicted objects and labels, and manage users and their permissions for collaborative image review

- Export images and labels for use in downstream data analysis/modeling and machine learning training.

Pytorch-Wildlife and MegaDetector, Camera Traps, Microsoft, 2025.
https://github.com/microsoft/CameraTraps/blob/main/megadetector.md
From the GitHub site:

> MegaDetector now resides in Pytorch-Wildlife as part of the model zoo.
>
> At the core of our mission is the desire to create a harmonious space where conservation scientists from all over the globe can unite. Where they're able to share, grow, use datasets and deep learning architectures for wildlife conservation. We've been inspired by the potential and capabilities of Megadetector, and we deeply value its contributions to the community. As we forge ahead with Pytorch-Wildlife, under which Megadetector now resides, please know that we remain committed to supporting, maintaining, and developing Megadetector, ensuring its continued relevance, expansion and utility.
>
> **MegaDetectorV6: SMALLER, FASTER, BETTER!**
> We have officially released our 6th version of MegaDetector, MegaDetectorV6! In the next generation of MegaDetector, we are focusing on computational efficiency, performance, modernizing of model architectures and licensing. We have trained multiple new models using different model architectures that are optimized for performance and low-budget devices, including Yolo-v9, Yolo-v10 and RT-Detr for maximum user flexibility. For example, the MegaDetectorV6-Ultralytics-YoloV10-Compact (MDV6-yolov10-c) model only have 2% of the parameters of the previous MegaDetectorV5 and still exhibits comparable performance on our validation datasets.

To test the newest version of MegaDetector with all the existing functionalities, you can use our Hugging Face interface or simply load the model with Pytorch-Wildlife. The weights will be automatically downloaded…

Timelapse, Saul Greenberg, 2024.
https://timelapse.ucalgary.ca/
From the website: Camera traps, remote cameras, field cameras and wildlife cameras are cameras strategically located in the field. They all capture activity at the camera's location over time. Each camera automatically takes an image or video at pre-set time intervals or through motion triggering. A set of cameras can easily collect thousands to millions of images.

The analyst's task. After retrieving the cameras' contents, analysts visually examine each image or video to turn it into data. Ecologists, for example, count and describe wildlife in the scene and conditions of interest (e.g., people, wildlife, weather).

The problem is that visually analyzing and encoding data from this multitude of images and videos is a painful process. Timelapse is a free software application that helps scientists do this last visual analysis and encoding step as efficiently as possible.

Yolo (You Only Look Once), Ultralytics, Inc., 2025.
https://docs.ultralytics.com/
From the website: Introducing Ultralytics YOLO11, the latest version of the acclaimed real-time object detection and image segmentation model. YOLO11 is built on cutting-edge advancements in deep learning and computer vision, offering unparalleled performance in terms of speed and accuracy. Its

streamlined design makes it suitable for various applications and easily adaptable to different hardware platforms, from edge devices to cloud APIs.

Explore the Ultralytics Docs, a comprehensive resource designed to help you understand and utilize its features and capabilities. Whether you are a seasoned machine learning practitioner or new to the field, this hub aims to maximize YOLO's potential in your projects.

Data Management Platforms, Web Platforms and Collaborative Networks

These platforms store, organize and manage camera trap image datasets, often supporting collaboration among multiple users or organizations. Many integrate with AI tools for species detection and allow for long-term data storage and sharing.

Agouti, Wageningen University and the Research Institute for Nature and Forest (INBO), undated.
https://agouti.eu/
From the website: By leveraging artificial intelligence, Agouti can automatically recognize many species and filter blank images. Agouti is a complete solution for organizations and professionals that use camera traps to survey wildlife. It lets camera trappers organize surveys, efficiently process images, obtain standardized output of the results, and safely archive your data. Agouti follows the Camera Trap Data Package [Camtrap DP] standard, a community developed data exchange format for camera trap data.

Workflow: After collecting cameras from the field, users upload the entire contents of the memory cards to Agouti. You enter the location and deployment details and Agouti automatically pulls timestamps and other metadata from the images, and groups images in sequences that represent the same event. You then have the option to apply one of our automatic species classification models, or inspect each image sequence manually and annotate them with one or more observations, using an easy interface.

Camelot, Camelot Project, undated.
https://camelotproject.org/
From the website:

Highlighted Features

- Easy to Use Database: Keeps track of camera trap, camera and species data.
- Easy Species Classification: Makes classifying camera trap images quick and easy.
- Free: Free and open-source camera trap software.
- Speed up identification with a beautiful and efficient interface.
- Support: Extensive documentation and quick technical support.
- Provides Reports for Analysis: Plays nicely with your preferred peer-reviewed camera trap software like PRESENCE and CamTrapR.
- Data Privacy: Your data is YOUR data. We NEVER see your data.
- Flexible: Lets multiple people use it at the same time.
- Reports: Flexible reports that can be used in your preferred analysis tool: PRESENCE, camtrapR.
- Image Metadata: Image metadata error checking features.

Trapper, Open Science Conservation Fund, 2020.
https://trapper-project.readthedocs.io/en/latest/overview.html
From the website: Trapper is an open source, django based web application to manage camera trapping projects. Motion-triggered camera trapping is increasingly becoming an important tool in ecological research. Because of the nature of collected data (multimedia files) even relatively small camera-trapping projects can generate large and complex datasets. The organization of these large collections of multimedia files and efficient querying for a particular subset of data, especially in a spatio-temporal context, is often a challenging task. Without an appropriate software solution this can become a serious data management problem, leading to delays and inaccessibility of data in the long run. We propose a new approach which, in contrast to available software solutions, is a fully open-source web application using spatially enabled data that can handle arbitrary media types (both pictures and videos), supports collaborative work on a project and data sharing between system users. We used state of the art and well-recognized open-source software components and modern, general purpose programming language Python to design a flexible software framework for data management in camera trapping studies.

Urban Wildlife Information Network, 2021.
https://www.urbanwildlifeinfo.org/
From the website: Every urban region is different, and each has its own unique suite of wildlife. The Urban Wildlife Institute (UWI) at Lincoln Park Zoo formed to conduct the science needed to ensure that humans and wildlife can co-exist in urban areas, and that cities can contribute to biodiversity conservation around the world. UWI pioneered new strategies for long-term data collection on urban species and has assembled the largest repository for urban wildlife data in the world. Though we have advanced scientific understanding about some urban-dwelling species, to holistically protect wildlife on an urbanizing planet we need to think much bigger.

Until recently it has been impossible to make comparisons across cities because there was no shared methodology, no mechanism for sharing data, and no framework for urban wildlife researchers to connect and compare their findings. The Urban Wildlife Information Network (UWIN) was created by UWI as an alliance of urban wildlife scientists committed to conducting research to enhance our knowledge of urban wildlife and their relationships with people.

We are seeking partners in cities around the world as we build the first global network collecting urban wildlife data. This network provides tools for scientists, city planners and wildlife managers to understand, conserve and manage wildlife on our rapidly urbanizing planet. Currently, UWIN has developed methodologies to collect, analyze and interpret wildlife data via camera trap surveys. Additional methods, such as acoustic monitoring and bird counts, can be integrated into camera trap data analyses. We are also interested in developing network wide protocols for other data collection methodologies so they too can be compared across cities.

Wildlife Insights, undated.
https://www.wildlifeinsights.org/
From the website:

> Wildlife Insights streamlines decision-making by providing machine learning models and other tools to manage, analyze and share camera trap data. With access to reliable data, everyone can make better decisions to help wildlife thrive.

A Quicker Way to Upload and Share

Anyone collecting camera trap photos can upload them to Wildlife Insights. Photos are stored online so you can access them from anywhere, from any device or computer, even out in the field.

Let a Computer do the Tagging

Animals in your photos are automatically identified using machine learning technology. Thousands of images can be tagged within minutes, saving you time to do the important work.

Create Maps and Graphs to Share

Access our suite of tools to analyze wildlife trends. Wildlife Insights can help your team make better decisions and share compelling findings.

Image and Metadata Organization Tools

These general-purpose tools are used to view, organize and manage large image collections. While not specific to wildlife monitoring, they can be used in camera trap workflows to manage image files and associated metadata.

Adobe Bridge, Adobe, 2025.
https://www.adobe.com/products/bridge.html
From the website: What can you do with Bridge?

- Edit metadata.
- Organize assets using collections, and find assets using powerful filters and advanced metadata search features.
- Add keywords, labels and ratings to assets.
- Collaborate with Creative Cloud Libraries and publish to Adobe Stock right from Bridge.

IrfanView, Irfan Skiljan, 2025.
https://www.irfanview.com/
From the website: IrfanView graphic viewer:

- Fast and compact (just 6 MB)
- Freeware for noncommercial use
- Supports Windows XP, Vista, 7, 8, 10 and 11
- 32 and 64 bit version
- Multi language support
- Unicode support
- Designed to be simple but powerful

Interoperability, Data Standards and Analytical Workflows

This category includes standards for structuring wildlife monitoring data and analytical tools — often in R — that process, manage and analyze camera trap datasets. Standards like Camtrap DP ensure data consistency and compatibility, while associated R packages provide functions for standardized analysis and reporting.

CameraTrapDetectoR, CameraTrapDetector Project, 2025.
https://github.com/CameraTrapDetectoR
From the GitHub site: The CameraTrapDetector project is a set of customized object detection deep learning models that identify, classify and count animals in camera trap images. The model can be run on personal computer as part of an existing workflow, saving time and preserving data privacy.
Our mission is to provide an accurate, easy-to-use, free computer vision tool to process large camera trap datasets. Users with no coding experience can automate the time-intensive task of classifying images, and optimize their time spent thinking analytically. Our tool enables researchers and land managers to perform analyses and make decisions faster and with more comprehensive information.

Camtrap DP (Camera Trap Data Package), Camtrap DP Development Team, undated.
https://camtrap-dp.tdwg.org/
Camtrap DP is a community-developed, standardized data exchange format that enables the transfer of camera trap data between platforms. *From the website:*

> Camtrap DP is a Frictionless Data Package that consists of:
>
> - Metadata about the data package and camera trap project.
> - Table with camera trap placements (deployments).
> - Table with media files recorded during deployments.
> - Table with observations derived from the media files.

"Camtrap DP: An Open Standard for the FAIR Exchange and Archiving of Camera Trap Data," Jakub W. Bubnicki, Ben Norton, Steven J. Baskauf, Tom Bruce, Francesca Cagnacci, Jim Casaer, Marcin Churski, Joris P. G. M. Cromsigt, Simone Dal Farra, Christian Fiderer, Tavis D. Forrester, Heidi Hendry, Marco Heurich, Tim R. Hofmeester, Patrick A. Jansen, Roland Kays, Dries P. J. Kuijper, Yorick Liefting, John D. C. Linnell, Matthew S. Luskin, Christopher Mann, Tanja Milotic, Peggy Newman, Jurgen Niedballa, Damiano Oldoni, Federico Ossi, Tim Robertson, Francesco Rovero, Marcus Rowcliffe, Lorenzo Seidenari, Izabela Stachowicz, Dan Stowell, Mathias W. Tobler, John Wieczorek, Fridolin Zimmermann and Peter Desmet, *Remote Sensing in Ecology and Conservation,* Vol. 10, Issue 3, pages 283-295, October 2023.
https://www.fs.usda.gov/rm/pubs_journals/2023/rmrs_2023_bubnicki_j001.pdf L
From the abstract: Although management and processing of camera trap-derived Big Data are becoming increasingly solvable with the help of scalable cyber-infrastructures, harmonization and exchange of the data remain limited, hindering its full potential. There is currently no widely accepted standard for exchanging camera trap data. The only existing proposal, "Camera Trap Metadata Standard" (CTMS), has several technical shortcomings and limited adoption. We present a new data exchange format, the Camera Trap Data Package (Camtrap DP), designed to allow users to easily exchange, harmonize and archive camera trap data at local to global scales. Camtrap DP structures camera trap data in a simple yet flexible data model consisting of three tables (Deployments, Media and Observations) that supports a wide range of camera deployment designs, classification techniques (e.g., human and AI, media-based and event-based) and analytical use cases, from compiling species occurrence data through distribution, occupancy and activity modeling to density estimation. The format further achieves interoperability by building upon existing standards, Frictionless Data Package in particular, which is supported by a suite of open software tools to read and validate data. Camtrap DP is the consensus of a long, in-depth, consultation and outreach process with standard and software developers, the main existing camera trap data management platforms, major players in the field of camera trapping and the Global Biodiversity Information Facility (GBIF). Under the umbrella of the Biodiversity Information Standards (TDWG), Camtrap DP has been developed openly, collaboratively and with version control from the start. We encourage camera trapping users and developers to join the discussion and contribute to the further development and adoption of this standard.

camtrapR: Camera Trap Data Management and Preparation of Occupancy and Spatial Capture-Recapture Analyses, The Comprehensive R Archive Network, undated.
https://CRAN.R-project.org/package=camtrapR
From the website: Management of and data extraction from camera trap data in wildlife studies. The package provides a workflow for storing and sorting camera trap photos (and videos), tabulates records of species and individuals, and creates detection/nondetection matrices for occupancy and spatial capture-recapture analyses with great flexibility. In addition, it can visualise species activity data and provides simple mapping functions with GIS export.

MLWIC2: Machine Learning for Wildlife Image Classification, Machine Learning for Wildlife Image Classification, 2025.
https://github.com/mikeyEcology/MLWIC2
From the GitHub site: MLWIC2 can be used to automatically classify camera trap images or to train new models for image classification, it contains two pre-trained models: the species_model identifies 58 species and empty images, and the empty_animal model distinguishes between images with animals and those that are empty. MLWIC2 also contains Shiny apps for running the functions.

Related Resource:

> **"Improving the Accessibility and Transferability of Machine Learning Algorithms for Identification of Animals in Camera Trap Images: MLWIC2,"** Michael A. Tabak, Mohammad S. Norouzzadeh, David W. Wolfson, Erica J. Newton, Raoul K. Boughton, Jacob S. Ivan, Eric Odell, Eric S. Newkirk, Reesa Y. Conrey, Jennifer Stenglein, Fabiola Iannarilli, John Erb, Ryan K. Brook, Amy J. Davis, Jesse Lewis, Daniel P. Walsh, James C. Beasley, Kurt C. Vercauteren, Jeff Clune and Ryan S. Miller, *Ecology and Evolution*, Vol. 10, Issue 19, pages 10374-10303, October 2020.
> https://onlinelibrary.wiley.com/doi/10.1002/ece3.6692
> *From the abstract:* Motion-activated wildlife cameras (or "camera traps") are frequently used to remotely and noninvasively observe animals. The vast number of images collected from camera trap projects has prompted some biologists to employ machine learning algorithms to automatically recognize species in these images, or at least filter-out images that do not contain animals. These approaches are often limited by model transferability, as a model trained to recognize species from one location might not work as well for the same species in different locations. Furthermore, these methods often require advanced computational skills, making them inaccessible to many biologists.
> ….
>
> Our software addresses some of the limitations of using machine learning to classify images from camera traps. By including many species from several locations, our species model is potentially applicable to many camera trap studies in North America. We also found that our empty-animal model can facilitate removal of images without animals globally. We provide the trained models in an R package (MLWIC2: Machine Learning for Wildlife Image Classification in R), which contains Shiny Applications that allow scientists with minimal programming experience to use trained models and train new models in six neural network architectures with varying depths.

Wildlife Tools, 2025.
https://github.com/WildlifeDatasets/wildlife-tools
From the GitHub site: The wildlife-tools library offers a simple interface for various tasks in the Wildlife Re-Identification domain. It covers use cases such as training, feature extraction, similarity calculation, image retrieval and classification. It complements the wildlife-datasets library, which acts as a dataset repository.

GIS and Field Data Collection Tools

The Esri tools described below support mapping, spatial analysis and field data collection. They are used to record and manage camera trap locations, integrate image data with GIS and conduct spatial analysis.

ArcGIS, Esri, undated.
https://www.esri.com/en-us/arcgis/geospatial-platform/overview
From the website: ArcGIS is a comprehensive geospatial platform for professionals and organizations. It is the leading geographic information system (GIS) technology. Built by Esri, ArcGIS integrates and connects data through the context of geography. It provides world-leading capabilities for creating, managing, analyzing, mapping and sharing all types of data. Organizations that use ArcGIS to understand and analyze their data in geographic context have a distinct advantage and decision-making edge.

ArcGIS Online, Esri, undated.
https://www.esri.com/en-us/arcgis/products/arcgis-online/overview
From the website: Accelerate geospatial insights: ArcGIS Online is a secure and scalable software as a service (SaaS) for your geospatial workflows. Improve decision-making by collecting and managing data, analyzing it, and easily sharing maps and apps within a connected and collaborative web geographic information system (GIS).

ArcCatalog, Esri, 2022.
https://desktop.arcgis.com/en/arcmap/latest/get-started/introduction/a-quick-tour-of-arccatalog.htm
From the website: The ArcCatalog application provides a catalog window that is used to organize and manage various types of geographic information for ArcGIS Desktop. ArcGIS Desktop is in mature support and will be retired March 1, 2026. There are no plans for future releases of ArcGIS Desktop, and it is recommended that you migrate to ArcGIS Pro. See Migrate from ArcMap to ArcGIS Pro for more information.

ArcGIS Pro, Esri, undated.
https://pro.arcgis.com/en/pro-app/latest/get-started/get-started.htm
From the website: ArcGIS Pro is a full-featured professional desktop GIS application from Esri. With ArcGIS Pro, you can explore, visualize and analyze data; create 2D maps and 3D scenes; and share your work to ArcGIS Online or your ArcGIS Enterprise portal. The sections below introduce the sign-in process, the start page, ArcGIS Pro projects and the user interface.

ArcGIS Field Maps, Esri, undated.
https://www.esri.com/en-us/arcgis/products/arcgis-field-maps/overview
From the website: ArcGIS Field Maps is an all-in-one app that uses data-driven maps and mobile forms to help workers perform data capture and editing, find assets and information, and report their real-time locations. ArcGIS Field Maps is the go-to field app that streamlines the critical workflows mobile personnel use every day. Because it is built on ArcGIS, everyone — whether in the field or the office — will benefit from using the same data.
ArcGIS Survey123, Esri, undated.
https://www.esri.com/en-us/arcgis/products/arcgis-survey123/overview?rsource=%2Fen-us%2Farcgis%2Fproducts%2Fsurvey123%2Foverview
From the website:

> **Transform everyday workflows with smart forms**
> Design smart forms and surveys with ArcGIS Survey123 — a dynamic form builder. Accelerate data collection and enhance the quality of results. Visualize and analyze information with a geographic

lens to better understand where and why things occur. Share data through web maps, apps and dashboards to inform decision-making and improve business processes.

Capabilities and Limitations of AI in Monitoring Wildlife

The publicly available research highlighted in this topic area examines how AI is transforming wildlife monitoring through faster image processing, species and individual identification and integration into camera trap workflows. Studies highlight the efficiency gains of AI tools and platform-based solutions, particularly for filtering empty images and detecting common species. However, these publications also emphasize challenges such as dataset, geographic and speciesist bias, reduced accuracy for rare or visually similar species and the need for human oversight. Citations are divided into two resource categories: domestic and international.

Domestic Resources

"Human Supervision is Key to Achieving Accurate AI-Assisted Wildlife Identifications in Camera Trap Images," Sarah E. Huebner, Meredith S. Palmer and Craig Packer, *Citizen Science: Theory and Practice,* Vol. 9, Issue 1, March 2024.
https://theoryandpractice.citizenscienceassociation.org/articles/10.5334/cstp.752
From the abstract: Using public support to extract information from vast datasets has become a popular method for accurately labeling wildlife data in camera trap (CT) images. However, the increasing demand for volunteer effort lengthens the time interval between data collection and our ability to draw ecological inferences or perform data-driven conservation actions. Artificial intelligence (AI) approaches are currently highly effective for species detection (i.e., whether an image contains animals or not) and labeling common species; however, it performs poorly on species rarely captured in images and those that are highly visually similar to one another. To capitalize on the best of human and AI classifying methods, we developed an integrated CT data pipeline in which AI provides an initial pass on labeling images, but is supervised and validated by humans (i.e., a "human-in-the-loop" approach). To assess classification accuracy gains, we compare the precision of species labels produced by AI and HITL protocols to a "gold standard" (GS) dataset annotated by wildlife experts. The accuracy of the AI method was species-dependent and positively correlated with the number of training images. The combined efforts of HITL led to error rates of less than 10% for 73% of the dataset and lowered the error rates for an additional 23%. For two visually similar species, human input resulted in higher error rates than AI. While integrating humans in the loop increases classification times relative to AI alone, the gains in accuracy suggest that this method is highly valuable for high-volume CT surveys.
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Microsoft has developed a tool called MegaDetector for classifying camera trap images as either empty or containing a human, vehicle, or animal. This tool is beneficial in eliminating camera trap images that do not contain any animals, thus cleaning the data and accelerating the classification process. Another tool called CameraTrapDetectoR has been created by Tabak et al. [9] using R language, that users can download and train with their data. However, unlike the aforementioned tools, the one developed in our study can classify both benchmark images and those taken from unseen locations, making it more practical for wildlife researchers and explorers of nature.

"Artificial Intelligence is Watching Wildlife," Andrew Vietze, *National Wildlife*, Spring 2024.
https://www.nwf.org/Magazines/National-Wildlife/2024/Spring/Conservation/Artificial-Intelligence-Wildlife-Conservation
In this article, the author discusses some of the ways in which AI is integrated into conservation efforts — and what the future might hold. *From the article:*

“But what’s truly the frontier right now,” says U.S. Geological Survey biologist Nathaniel Hitt, “is not the identification of species but the identification of individuals.” In Hitt’s case, those individuals are brook trout, but he relies on the same — often controversial — technology that’s used in human facial recognition. “Identifying individuals is necessary, of course, for conservation biology,” he says. “If you want to estimate trends in abundance, you need to know if you’re counting the same fish more than once.”

“Speciesist Bias in AI: How AI Applications Perpetuate Discrimination and Unfair Outcomes Against Animals,” Thilo Hagendorff, Leonie N. Bossert, Yip Fai Tse and Peter Singer, *AI and Ethics,* Vol. 3, pages 717-734, 2023.
https://link.springer.com/article/10.1007/s43681-022-00199-9
From the abstract: Massive efforts are made to reduce biases in both data and algorithms to render AI applications fair. These efforts are propelled by various high-profile cases where biased algorithmic decision-making caused harm to women, people of color, minorities, etc. However, the AI fairness field still succumbs to a blind spot, namely its insensitivity to discrimination against animals. This paper is a critical comment on current fairness research in AI. It is the first to describe the ‘speciesist bias’ and investigate it in several different AI systems by reflecting on the problem via a normative analysis and by probing, in several case studies, image recognition, word embedding, and language models with established methods for bias detection. We claim that animals matter morally and that discriminating against them is unethical. Furthermore, we provide evidence for speciesist biases in all the mentioned areas of AI. We find that speciesist biases are solidified by many mainstream AI applications, especially in the fields of computer vision as well as natural language processing. In both cases, this occurs because the models are trained on datasets in which speciesist patterns prevail. Therefore, AI technologies currently play a significant role in perpetuating and normalizing violence against animals. To change this, AI fairness frameworks must widen their scope and include mitigation measures for speciesist biases. This paper addresses the AI community in this regard and stresses the influence AI systems can have on either increasing or reducing the violence that is inflicted on animals, especially on farmed animals.

“An Evaluation of Platforms for Processing Camera-Trap Data Using Artificial Intelligence,” Juliana Vélez, William McShea, Hila Shamon, Paula J. Castiblanco-Camacho, Michael A. Tabak, Carl Chalmers, Paul Fergus and John Fieberg, *Methods in Ecology and Evolution; Special Feature: Leveraging Natural History Collections to Understand the Impacts of Global Change*, Vol. 14, Issue 2, pages 459-477, February 2023.
https://besjournals.onlinelibrary.wiley.com/doi/epdf/10.1111/2041-210X.14044
From the abstract:

1. Camera traps have quickly transformed the way in which many ecologists study the distribution of wildlife species, their activity patterns and interactions among members of the same ecological community. Although they provide a cost-effective method for monitoring multiple species over large spatial and temporal scales, the time required to process the data can limit the efficiency of camera-trap surveys. Thus, there has been considerable attention given to the use of artificial intelligence (AI), specifically deep learning, to help process camera-trap data. Using deep learning for these applications involves training algorithms, such as convolutional neural networks (CNNs), to use particular features in the camera-trap images to automatically detect objects (e.g., animals, humans, vehicles) and to classify species.
2. To help overcome the technical challenges associated with training CNNs, several research communities have recently developed platforms that incorporate deep learning in easy-to-use interfaces. We review key characteristics of four AI platforms — Conservation AI, MegaDetector, MLWIC2: Machine Learning for Wildlife Image Classification and Wildlife Insights — and two

auxiliary platforms — Camelot and Timelapse — that incorporate AI output for processing camera-trap data. We compare their software and programming requirements, AI features, data management tools and output format. We also provide R code and data from our own work to demonstrate how users can evaluate model performance.

3. We found that species classifications from Conservation AI, MLWIC2 and Wildlife Insights generally had low to moderate recall. Yet, the precision for some species and higher taxonomic groups was high, and MegaDetector and MLWIC2 had high precision and recall when classifying images as either 'blank' or 'animal.' These results suggest that most users will need to review AI predictions, but that AI platforms can improve efficiency of camera-trap-data processing by allowing users to filter their dataset into subsets (e.g., of certain taxonomic groups or blanks) that can be verified using bulk actions.
4. By reviewing features of popular AI-powered platforms and sharing an open-source GitBook that illustrates how to manage AI output to evaluate model performance, we hope to facilitate ecologists' use of AI to process camera-trap data.

"Human vs. Machine: Detecting Wildlife in Camera Trap Images," Scott Leorna and Todd Brinkman, *Ecological Informatics*, Vol. 72, December 2022.
https://doi.org/10.1016/j.ecoinf.2022.101876
From the abstract: To expedite camera trap image processing, many have turned to the field of artificial intelligence (AI) and use machine learning models to automate tasks such as detecting and classifying wildlife in images. To contribute understanding of the utility of AI tools for processing wildlife camera trap images, we evaluated the performance of a state-of-the-art computer vision model developed by Microsoft AI for Earth named MegaDetector using data from an ongoing camera trap study in Arctic Alaska, USA. Compared to image labels determined by manual human review, we found MegaDetector reliably determined the presence or absence of wildlife in images generated by motion detection camera settings (≥94.6% accuracy), however, performance was substantially poorer for images collected with time-lapse camera settings (≤61.6% accuracy). By examining time-lapse images where MegaDetector failed to detect wildlife, we gained practical insights into animal size and distance detection limits and discuss how those may impact the performance of MegaDetector in other systems. We anticipate our findings will stimulate critical thinking about the tradeoffs of using automated AI tools or manual human review to process camera trap images and help to inform effective implementation of study designs.

International Resources

"Chapter 14: Limitations and Challenges of AI in Wildlife Conservation," Archna Goyal, Ruchika Bhakhar and Surbhi Singh, *AI and Machine Learning Techniques for Wildlife Conservation,* pages 363-394, January 2025.
https://www.researchgate.net/publication/388891662_Limitations_and_Challenges_of_AI_in_Wildlife_Conservation
From the abstract: This chapter examines AI's potential to enhance wildlife conservation, focusing on applications like species identification, habitat suitability modeling, anti-poaching efforts and automated monitoring. It highlights successful case studies and real-world uses but also addresses significant challenges such as data constraints, ethical concerns, high costs and technological barriers that may limit AI's full impact in conservation efforts. The chapter also reviews gaps in current literature and methodologies, pointing to a pressing need for enhanced data quality, interdisciplinary collaboration and robust ethical guidelines. Emphasizing that AI's integration must be sustainable, the chapter concludes that achieving a balance between technological innovation and ecological integrity is essential

to realize AI's transformative potential for global conservation efforts. Ultimately, strategic partnerships and ongoing research will be crucial for scaling AI's role in biodiversity preservation.

"Machine Learning Tool for Wildlife Image Classification," Karoline Seljebotn and Isah A. Lawal, *ICMLT '24: Proceedings of the 2024 9th International Conference on Machine Learning Technologies,* pages 127-132, September 2024.
https://dl.acm.org/doi/pdf/10.1145/3674029.3674050
From the abstract: This study introduces a new method for classifying animals in both benchmark and camera trap images using a single model. The model achieved a top-1 accuracy of 93% for benchmark images and 56% for camera trap images previously unseen. The model was integrated into a web application, making it accessible to wildlife researchers without programming knowledge.

From Related Work on page 1 of the article: One limitation with models trained to classify camera trap images is that they are typically only trained with images from a limited number of locations. As a result, species from one area that are correctly labeled by a model may not be recognizable by another model trained with data from another area [3]. Thus limiting the use of the models as a stand-alone tool without human verification of the outputs.

"Integrating AI Ethics in Wildlife Conservation AI Systems in South Africa: A Review, Challenges and Future Research Agenda," Irene Nandutu, Marcellin Atemkeng and Patrice Okouma, *AI and Society,* Vol. 38, pages 245-257, September 2021.
https://link.springer.com/article/10.1007/s00146-021-01285-y
From the abstract: With the increased use of Artificial Intelligence (AI) in wildlife conservation, issues around whether AI-based monitoring tools in wildlife conservation comply with standards regarding AI Ethics are on the rise. This review aims to summarise current debates and identify gaps as well as suggest future research by investigating (1) current AI Ethics and AI Ethics issues in wildlife conservation, (2) Initiatives Stakeholders in AI for wildlife conservation should consider integrating AI Ethics in wildlife conservation. We find that the existing literature weakly focuses on AI Ethics and AI Ethics in wildlife conservation while at the same time ignores AI Ethics integration in AI systems for wildlife conservation. This paper formulates an ethically aligned AI system framework and discusses pre-eminent on-demand AI systems in wildlife conservation. The proposed framework uses agile software life cycle methodology to implement guidelines towards the ethical upgrade of any existing AI system or the development of any new ethically aligned AI system. The guidelines enforce, among others, the minimisation of intentional harm and bias, diversity in data collection, design compliance, auditing of all activities in the framework and ease of code inspection. This framework will inform AI developers, users, conservationists and policymakers on what to consider when integrating AI Ethics into AI-based systems for wildlife conservation.

"Use of Object Detection in Camera Trap Image Identification: Assessing a Method to Rapidly and Accurately Classify Human and Animal Detections for Research and Application in Recreation Ecology," Mitchell Fennell, Christopher Beirne and A. Cole Burton, *Global Ecology and Conservation,* Vol. 35, June 2022.
https://doi.org/10.1016/j.gecco.2022.e02104
From the abstract: We applied an object detection model (MegaDetector) to camera trap data from a study of recreation ecology in British Columbia, Canada. We tested its performance in detecting humans and animals relative to manual image classifications, and assessed efficiency by comparing the time required for manual classification versus a modified workflow integrating object detection with manual classification. We also evaluated the reliability of using MegaDetector to create an index of human activity for application to the study of recreation impacts to wildlife.

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Our test of an open-source object detection model showed it performed well in partially classifying a camera trap dataset, significantly increasing processing efficiency. We suggest that this tool could be integrated into existing camera trap workflows to accelerate research and application by alleviating data bottlenecks, particularly for surveys processing large volumes of human images. We also show how the model and workflow can be used to anonymize human images prior to classification, protecting individual privacy.

Emerging AI-Integrated Systems for Wildlife Monitoring

The research cited below highlights advances in integrating AI directly into wildlife monitoring systems, paving the way for "smart" camera traps and fully automated monitoring networks. Innovations include on-device AI processing for adaptive, long-term autonomous operation, privacy protection and poacher detection, as well as large-scale solar-powered camera networks with real-time data transmission, remote system management and automated species identification.

"Reliable and Efficient Integration of AI Into Camera Traps for Smart Wildlife Monitoring Based on Continual Learning," Delia Velasco-Montero, Jorge Fernández-Berni, Ricardo Carmona-Galán, Ariadna Sanglas and Francisco Palomares, *Ecological Informatics,* Vol. 83, November 2024.
https://doi.org/10.1016/j.ecoinf.2024.102815
From the abstract: In this paper, we comprehensively report on an efficient approach for the integration of artificial intelligence (AI) processing pipelines in camera traps for smart on-site wildlife monitoring. Our work covers hardware, software and algorithmics.

From Section 6, Learned lessons: Challenges and opportunities (page 13 of the PDF): This manuscript is the first milestone in our long-term research aiming at the realization of smart camera traps capable of automatically adapting to the environment and generating meaningful periodic reports over long periods of autonomous operation. Concerning data privacy and ethical operation, one advantage of incorporating intelligence directly into the device itself is the ability to implement measures such as person filtering to preserve privacy or person detection to identify the presence of poachers. In general, the capabilities of the proposed system can be put, as far as possible, at disposal of the realization of codes of conduct such as the one outlined in (Sharma et al., 2020) for use of camera traps in wildlife research.

"Development of a Cost-Efficient Automated Wildlife Camera Network in a European Natura 2000 Site," W. Daniel Kissling, Julian C. Evans, Rotem Zilber, Tom D. Breeze, Stacy Shinneman, Lindy C. Schneider, Carl Chalmers, Paul Fergus, Serge Wich and Luc H.W.T. Geelen, *Basic and Applied Ecology,* Vol. 79, pages 141-152, September 2024.
https://doi.org/10.1016/j.baae.2024.06.006
From the abstract: Modern approaches with advanced technology can automate and expand the extent and resolution of biodiversity monitoring. We present the development of an innovative system for automated wildlife monitoring in a coastal Natura 2000 nature reserve of the Netherlands with 65 wireless 4G wildlife cameras which are deployed autonomously in the field with 12 V/2A solar panels, i.e., without the need to replace batteries or manually retrieve SD cards. The cameras transmit images automatically (through a mobile network) to a sensor portal, which contains a PostgreSQL database and functionalities for automated task scheduling and data management, allowing scientists and site managers via a web interface to view images and remotely monitor sensor performance (e.g. number of uploaded files, battery status and SD card storage of cameras). The camera trap sampling design combines a grid-based sampling stratified by major habitats with the camera placement along a

traditional monitoring route, and with an experimental set-up inside and outside large herbivore exclosures. This provides opportunities for studying the distribution, habitat use, activity, phenology, population structure and community composition of wildlife species and allows comparison of traditional with novel monitoring approaches. Images are transferred via application programming interfaces to external services for automated species identification and long-term data storage. A deep learning model for species identification was tested and showed promising results for identifying focal species. Furthermore, a detailed cost analysis revealed that establishment costs of the automated system are higher but the annual operating costs much lower than those for traditional camera trapping, resulting in the automated system being >40 % more cost-efficient. The developed end-to-end data pipeline demonstrates that continuous monitoring with automated wildlife camera networks is feasible and cost-efficient, with multiple benefits for extending the current monitoring methods. The system can be applied in open habitats of other nature reserves with mobile network coverage.

Contacts

CTC engaged with the individuals below to gather information for this investigation.

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Note: Vishal Subramanyan is also a team member of the California Wolf Project within University of California Berkeley’s Rausser College of Natural Resources.

Appendix A: Survey Questions

Two online surveys, represented below, were sent to experts with experience using photo recognition software and database software programs to process and manage camera trap images. Respondents included private sector, state agency and university professionals.

Caltrans Survey on Wildlife Connectivity Innovation
The California Department of Transportation (Caltrans) is gathering information about the available technologies and use of artificial intelligence to gather, accurately process, track and share vast amounts of photographic data. This data is used to inventory and monitor wildlife barriers statewide.

The survey below inquires about your experience with [*photo recognition software used to inventory and monitor wildlife* OR *database software programs used for long-term storage and information sharing*]. We estimate the survey will take [*15 minutes* OR *10 minutes, respectively*] to complete. We would appreciate receiving your responses by **Friday, May 9**.

The final report for this project, which will include a summary of the responses received from all survey participants, will be available on the Caltrans website.

If you have questions about completing the survey, please contact Chris Kline at chris.kline@ctcandassociates.com. If you have questions about Caltrans' interest in this issue, please contact Tori Kanzler at tori.kanzler@dot.ca.gov.

Thanks very much for your participation!

(Required) Please provide your contact information.

Name:
Agency:
Email Address:
Phone Number:

Questions for Photo Recognition Software Program Experts

All Camera Software

1. Please describe the photo recognition software programs that you have experience using.
2. What is/was your purpose or goal when using camera trap photos (e.g., presence/absence, abundance, distribution, other)?
3. Are the software programs you have used geared toward specific species or locations?
4. Are there fees for use? If yes, please describe these fees.

Preferred Camera Software

1. Which camera software program(s) do you prefer and why?
2. Please describe the photo upload process.
3. Approximately how many photos are you uploading at a time and how many photos overall?
4. Please describe the level of difficulty associated with the upload process.
5. How much quality assurance/quality control (QA/QC) is required to have confidence in output?

6. Please describe your level of confidence in the program’s ability to identify species to meet your project goals.
7. Has the program demonstrated learning? Is there a reduction of QA/QC needed over time? Please describe.
8. What feature do you like the most?
9. What feature do you like the least?
10. Does the program perform statistical analysis? If yes, please describe the statistical analysis.
11. Can multiple users log into the same account at the same time? If yes, please indicate how many simultaneous users the software permits.
12. Does the program result in overall time savings and improved organization of photo data? If yes, please describe these benefits.
13. Is there something you wish the program would do that it currently does not? If yes, please describe the desired system features.
14. What else does Caltrans need to know that we haven’t addressed in the questions above?

Questions for Database Software Program Experts

1. Please describe the database software programs you have used.
2. What was the goal or purpose for deploying the database?
3. Which database software program do you prefer and why?

Note: Please answer the following questions as they relate to your preferred database software program.

1. Please describe the level of difficulty in using the software.
2. Please describe quality assurance/quality control (QA/QC) needs for the data.
3. What feature do you like the most?
4. What feature do you like the least?
5. Does the program perform statistical analysis? If yes, please describe the statistical analysis.
6. Can multiple users log into the same account at the same time? If yes, please indicate how many simultaneous users the software permits.
7. Does the database software incorporate GIS?
8. Is there something you wish the program would do that it currently does not? If yes, please describe the desired system features.
9. What else does Caltrans need to know that we haven’t addressed in the questions above?