Animal Biotelemetry

An open Web-based system for the analysis and sharing of animal tracking data

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Abstract

Background: Improvements in telemetry technology are allowing us to monitor animal movements with increasing accuracy, precision and frequency. The increased complexity of the data collections, however, demands additional software and programming skills to process, store and disseminate the datasets. Recent focus on data availability has also heightened the need for sustainable data management solutions to ensure data integrity and provide longer term access. In the last ten years, a number of online facilities have been developed for the archiving, processing and sharing of telemetry data. These facilities offer secure storage, multi-user support and analysis tools and are a step along the way to improving data access, long-term data preservation and science communication. While these software platforms promote data sharing, access to the majority of the data and to the software behind these systems remains restricted. In this paper, we present a comprehensive, highly accessible and fully transparent software facility for animal movement data.

Results: The online system we developed (http://oztrack.org) offers a set of robust, up-to-date and accessible tools for managing, processing, visualising and analysing animal location data and linking these outputs with environmental datasets. As OzTrack uses exclusively free and open-source software, and the source code is available online, the system promotes open access not only to data but also to the tools and software underpinning the system.

Conclusions: We outline the capabilities and limitations of the infrastructure design and discuss the uptake of this platform by the Australasian biotelemetry community. We discuss whether an open approach to analysis tools and software encourages a more open approach to sharing data, information and knowledge. Finally, we discuss why a free and open approach enhances longer term sustainability and enables data storage facilities to evolve in parallel with the telemetry devices themselves.

Keywords: Electronic tagging, Electronic tags, Environmental data, GPS, Information management, Kalman filter, Movement ecology, Open access, OzTrack, PostgreSQL, PostGIS, R, Relational database, Tracking software, VHF, Wildlife monitoring

Background

Animal biotelemetry is a dynamic and rapidly evolving field of ecology. The number of publications featuring the use of telemetric devices to provide fundamental insights into a species' ecology has increased steadily over the past 30 years [1,2]. Technological advancement during this time has improved positional accuracy and is allowing the collection of more frequent location fixes over longer time periods [3,4]. Furthermore, tag size and weight have substantially reduced [5], as has unit cost [6], broadening the spectrum of species and life stages that can be studied. These developments in tracking technology and data acquisition have reduced the effort required to gather high-quality animal location data, providing researchers with an opportunity to build a coherent picture of how animals behave within their natural environment.

The relative ease and low cost by which temporally dense sets of animal locations can now be collected is increasing the volume of data collected and thus making effective management of the data challenging. Telemetry devices now routinely generate datasets that are larger than off-the-shelf software tools or spreadsheet applications can handle [7,8]. While dedicated, proprietary

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software platforms for processing these tracking data are available directly from the tag manufacturers, many large-scale and long-term studies utilise tags sourced from multiple manufacturers (e.g. [9,10]). In this scenario, a number of independent applications may be required; these include software tools designed for spatial data management and visualisation, as well as tools to filter and analyse spatiotemporal datasets. Typically, this requires data replication and export/import procedures across multiple software applications, which can be time-consuming and prone to error and duplication [11].

To ensure data persistence and to facilitate comparative studies across species and localities, the secure, consistent and efficient management of data is essential. If raw data are stored locally in personal databases, they are at risk of being lost or discarded due to disk failure or the data owner changing offices or careers. As data are collected as a result of disturbing animals, and many programs are funded by public money, there is a responsibility for the researcher to provide public access to their data once funding and publishing obligations have been met [12,13]. Data publishing is already a high priority in many fields, and many research journals and funding bodies now require that data supporting the results of studies are archived in an appropriate public archive which guarantees their re-use and preservation [14].

While some researchers may be unwilling to transfer their datasets into an online data repository (e.g. for fear of others misusing their data or using it without proper acknowledgement [15]), data management and dissemination through the Internet offers some clear advantages. For example, ongoing telemetric studies may require updating on a regular basis with new data and recent deployments [16], and project collaborators may want to be kept informed on the study's progress and the current whereabouts of tagged animals. The data may be useful for educational or public outreach purposes, which can increase the profile of the research through mass media and articles in national and international news outlets [17]. Increased data transparency may also stimulate collaboration, through the sharing of data between research groups and specialists in the same or related fields. This increased synergy may reduce the need to collect further or new data and can lead to academic as well as financial gains [14,18]. While a number of groups have succeeded in developing their own infrastructure for this purpose (e.g. Whalenet [19], the Narragansett Bay Coyote Study [20], the Information System for the Analysis and Management of Ungulate Data [21]), developing such infrastructure requires considerable time and resources, including collaborative input from information technology (IT) and e-Science experts.

In recognition of these challenges, some wildlife biologists have stressed a need for free online facilities with standardised tools and techniques for telemetry data [11,17,22]. These facilities should not be limited to data management but should also support the analysis, visualisation and sharing of animal tracking data. A number of Web-based animal telemetry data repositories are currently available for this purpose. These include Movebank [23], OBIS-SEAMAP (Ocean Biogeographic Information System-Spatial Ecological Analysis of Megavertebrate Populations) [24], Wildlife Tracking (formerly Seaturtle.org) [17], Wireless Remote Animal Monitoring [25] and the European Roe Deer project [26]. Data within these repositories are stored in a way which permits multi-user support and data sharing, a secure and consistent storage system and analysis and filtering tools of varying complexity. However, the data policies of these facilities are still restrictive [13], with only a small fraction of contributed datasets accessible for downloading or viewing. Furthermore, the infrastructure underlying these repositories remains guarded (or focused on a single species), reducing the potential for the examination and further development of these tools by the wider biotelemetry community.

In this paper, we introduce an online platform based on a spatially enabled database management system (DBMS) for the archiving, analysis and dissemination of multi-species tracking data: OzTrack.org [27,28]. Our main objectives were twofold. The first objective was to develop a free, open source, highly accessible yet comprehensive Web-based application with automated procedures and tools for processing animal location data. Our second objective was to increase data and metadata visibility, thereby encouraging a data sharing culture amongst the animal tracking community. These objectives were achieved through a collaborative partnership between biologists and software engineers based at The University of Queensland, and a steering committee comprising researchers and practitioners of wildlife telemetry and eResearch services. Researchers conducting biotelemetry studies now have access to the tools and contributed telemetry datasets resulting from this collaboration. Here, we provide a description of the software architecture, discuss system uptake and illustrate system functionality using existing OzTrack projects. Finally, we discuss future developments and argue why an open-access approach to data, analysis tools and software is fundamental if we are to keep up with the rapid advancement of the devices themselves.

Methods

The database management system

The OzTrack system was implemented using the open-source object-relational database system PostgreSQL [29] (version 9.1), with its spatial extension PostGIS [30] (version 2.0). These tools were overlaid within a Java Web application and a user-friendly Web interface constructed to enable project creation and metadata upload (Figure 1). The input process is straightforward: project metadata is
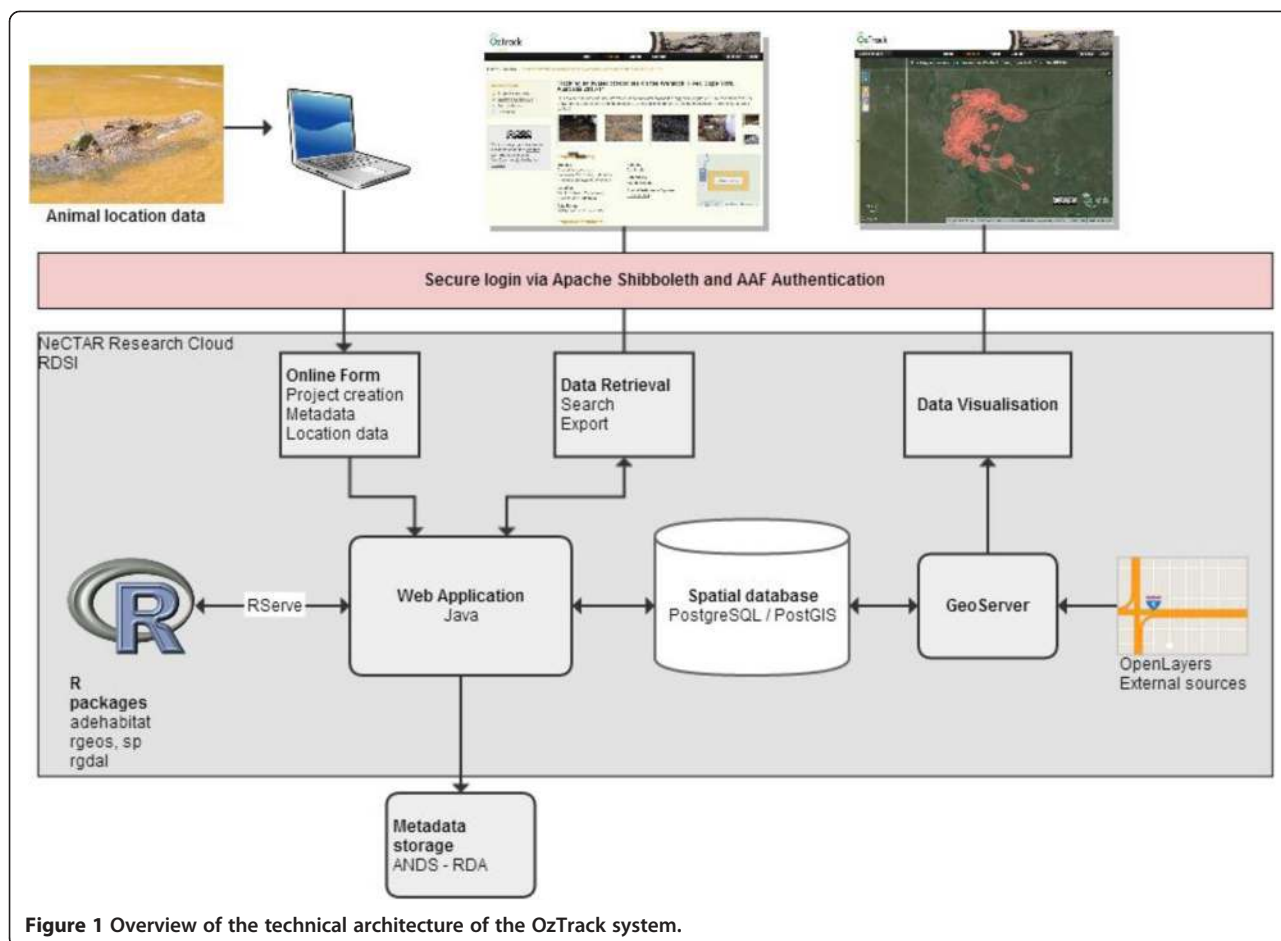
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Figure 1 Overview of the technical architecture of the OzTrack system.

entered via an online form, with animal location data uploaded in Comma-Separated Value (.CSV) or Microsoft Excel (.XLS) files. To increase system flexibility, animal location datasets may be uploaded with dates and times in the format "dd/mm/yyyy HH:MM" or "yyyy-mm-dd HH: MM:SS" and geographical coordinates as decimal degrees, degrees decimal minutes or degrees minutes seconds in the World Geodetic System (WGS) 1984 datum. The entry of a species' common name and species' scientific name is automated using the Atlas of Living Australia Autocomplete Web service [31]. There is also the option for users to enter the species' common and scientific name manually, increasing the transferability to study outside of Australia. Metadata describing data collections, users and projects within the system are published to Australian National Data Service-Research Data Australia (ANDS-RDA) in the Registry Interchange Format—Collections and Services (RIF-CS) metadata format. The OzTrack system is hosted on server infrastructure within the National eResearch Collaboration Tools and Resources (NeCTAR) Research Cloud. This greatly reduced the administration costs and effort compared with hosting the system locally.

Mapping functionality

Interactive mapping and visualisation services were obtained from the open-source GeoServer software server [32], providing a consistent interface for rendering maps and feature data. Data are visualised via an in-browser OpenLayers map, which includes Google Maps base imagery, and measure and zoom functionality (Figure 1). Climatic, environmental and political spatial layers were obtained from online remote sensing repositories covering both the terrestrial and the marine environments (Additional file 1: Table S1). Layers are rendered as raster images on the server side using GeoServer, which are then visualised as Portable Network Graphics (.PNG) image tiles at the required zoom level. This feature was found to dramatically speed up the processing time, particularly for datasets containing large numbers of location fixes (e.g. those approaching 10,000 detections) [27]. Requests for map tiles, feature attributes and map legends were developed using GeoServer's WMS interface. Once visualised, Structured Query Language (SQL) statements are used to query the animal locations, trajectories and spatial layers. Full details on the implementation of these tools, and the

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underlying code, can be found on the OzTrack GitHub website [33].

Analysis tools

Once location data are uploaded into a project, movement metrics such as the total number of fixes per deployment, the mean number of fixes per day, animal step length and the minimum distance travelled are extracted automatically using a series of SQL statements. Standard filtering options for data visualisation and analysis were implemented using update statements in SQL, such as setting a start and end date or tag location quality (i.e. Argos location class, dilution of precision class). OzTrack also provides a polygon selection tool permitting the user to manually delete improbable location estimates (e.g. an inland location for a marine species) from a project. To perform more complex spatial analyses and data filtering procedures, the system connects to the R programming environment [34] via RServe [35]. Spatial analysis and filtering tools contained within contributed R packages (Table 1, Additional file 2: Table S2), and our own customised R code and R-Forge (a R

interface to GDAL, OGR and PROJ.4) are all called inside the OzTrack system as native procedures (Figure 1). Support regarding the parameterisation of the analysis and filter tools can be found in the form of help icons positioned next to the appropriate tool or through links provided to the R package help files, vignettes and publications via the system's Web portal [33]. Spatial distances are calculated as great circle distances on the WGS 1984 ellipsoid, and area calculations are performed after locations are converted from this geographical coordinate system into a suitable projected spatial reference system (SRS). SRS conversions are conducted using PROJ.4 projection arguments in the rgdal R package [36], with EPSG codes obtained from spatialreference.org [37]. The results of these procedures (i.e. vector-based objects: points, lines or polygons) are returned to OzTrack using the Keyhole Markup Language (KML) format via RServe for visualisation.

All capture and tagging procedures were carried out with approval from The University of Queensland Animal Ethics Committee (Cassowaries:SIB/935/08/EPA ; Crocodiles: SBS/204/11/ARC/AUST ZOO; Koalas: CMLR/091/

Table 1 Current tool functionality and data formats for export

Tool	Description	Exportable format
Editing tools		
Polygon selection	Manual selection of locations for removal by drawing polygons.	.CSV, .KML, .SHP
Date filter	Filter locations by date range.	.CSV, .KML, .SHP
Location class filter	Locations with a lower location accuracy than the minimum specified will be deleted.	.CSV, .KML, .SHP
Speed filter	Locations that imply the animal has exceeded the specified maximum speed will be deleted.	.CSV, .KML, .SHP
Kalman filter	This filter applies a state-space model combined with a Kalman filter to the location data to predict the "most probable" track.	.CSV, .KML, .SHP
Kalman filtered data (SST)	This filter applies a state-space model combined with a Kalman filter to the location and temperature sensor data predict the 'most probable' track. The tag-recorded SST is matched with external SST data collected by the National Oceanic and Atmospheric Administration.	.CSV, .KML, .SHP
Analysis tools		
Movement metrics	Track distance, mean step length and mean step speed are extracted using the great circle distance algorithm.	-
Minimum convex polygon	A home range measure which uses the smallest area convex set that contains the location data.	.KML, .SHP
Kernel utilisation distribution	A home range measure which uses the utilisation distribution to estimate the probability that an animal will be found at a specific geographical location.	.KML, .SHP
Kernel Brownian bridge	A home range measure which uses the utilisation distribution to estimate the probability that an animal will be found at a specific geographical location. Unlike the fixed kernel approach, the Kernel Brownian Bridge incorporates serial autocorrelation between fixes into the estimate.	.KML, .SHP
Alpha hull	A generalisation of the convex hull, which uses Delaunay triangulation to objectively crop low use areas from a polygon surface.	.KML, .SHP
Local convex hull	A home range measure which creates utilisation distributions based on the local nearest-neighbour convex hulls. These are formed by constructing convex hulls around each location in the animal's trajectory then jointing these hulls together, iteratively, to form isopleths.	.KML, .SHP
Heat map	This tool generates a grid over the study area and uses a coloured gradient to visually identify areas of high usage by the tagged animal. Can be applied to either points or connectivity lines between points.	.KML, .SHP

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12/ARC/RIO TINTO) and a Queensland Government permits (Cassowaries: DERM 2011/02/01; Crocodiles: WISP05268508; Koalas: WISP05609708).

Results and discussion

System uptake

At the time of writing (February 2014), the Web site has recorded 3,298 site visits (comprising 4,603 page views) and 92 registered users (including academics, university students, agency scientists and environmental consultants). In total, 1,417 tracks comprising 2,050,812 position fixes from 55 different species have been uploaded, with location data gathered using telemetric devices (i.e.

Argos, GPS, VHF, light-based geolocations and underwater acoustic), or re-sightings of individually marked animals.

During its development, OzTrack.org was used productively by a number of research groups and organisations to address a range of wildlife management and conservation scenarios. This included facilitating the visualisation of movements and generating home range estimates for koalas (*Phascolarctos cinereus*) inhabiting a highly fragmented landscape in South East Queensland, Australia (Figure 2). Here, OzTrack enabled researchers to construct home ranges and identify cleared areas where koalas fitted with GPS collars regularly crossed between habitat fragments. The findings from this study were used to focus habitat restoration activities on
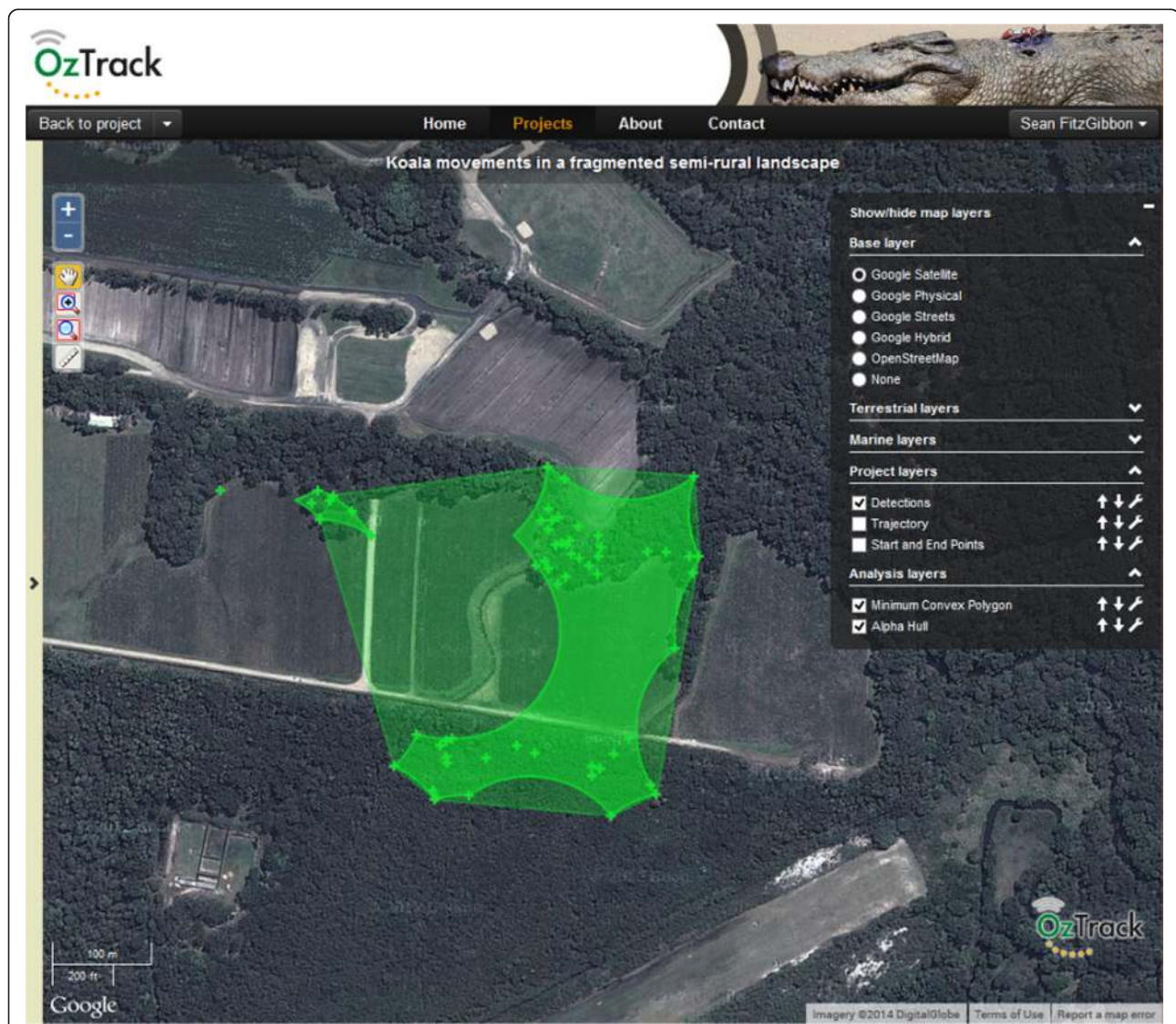

Figure 2 The locations and home range estimates of a GPS-collared koala in a highly fragmented landscape. Home ranges estimated using minimum convex polygon (MCP) and alpha hull methods. The locations are projected onto a Google satellite base layer and visualised within the OzTrack system portal.
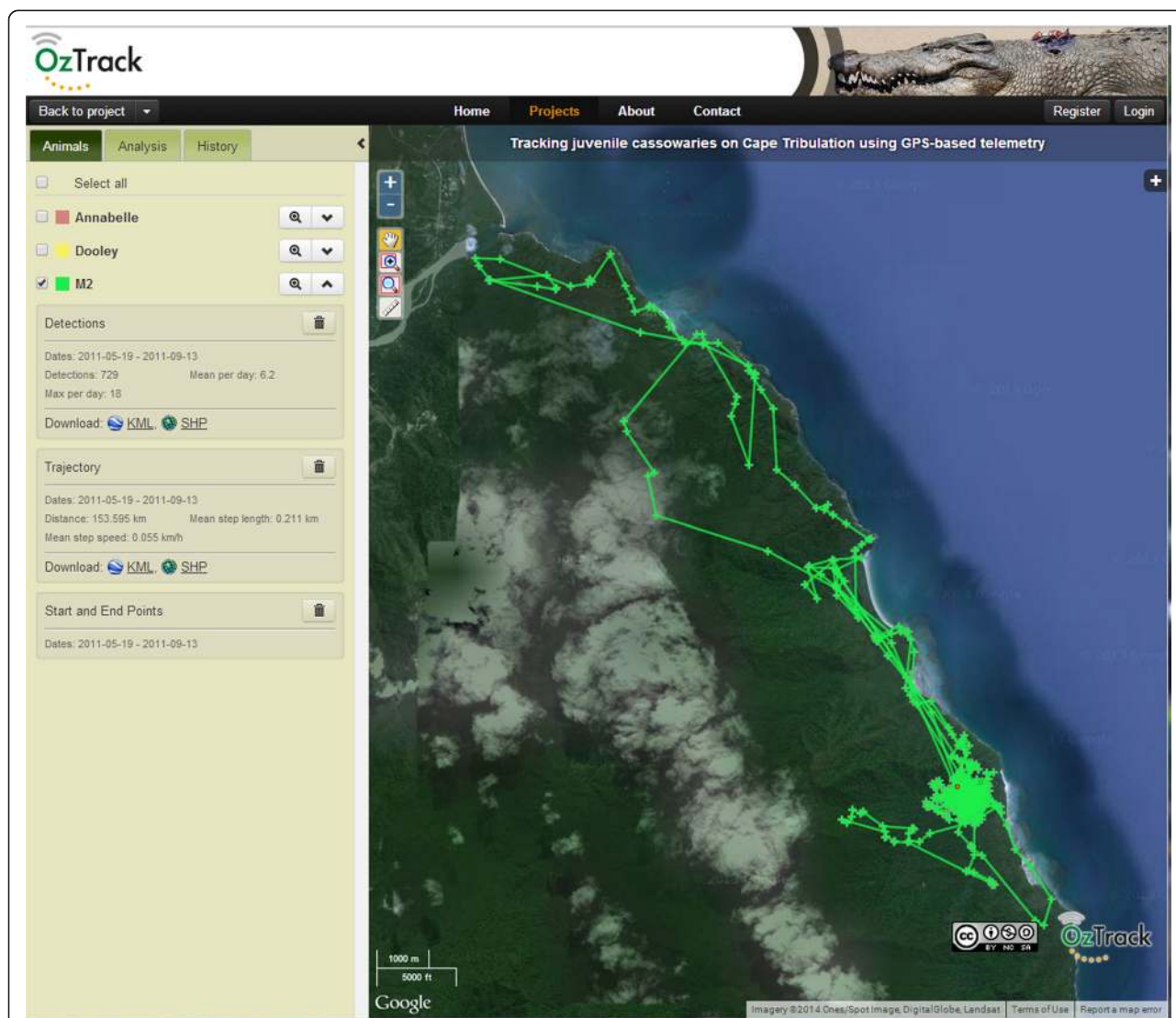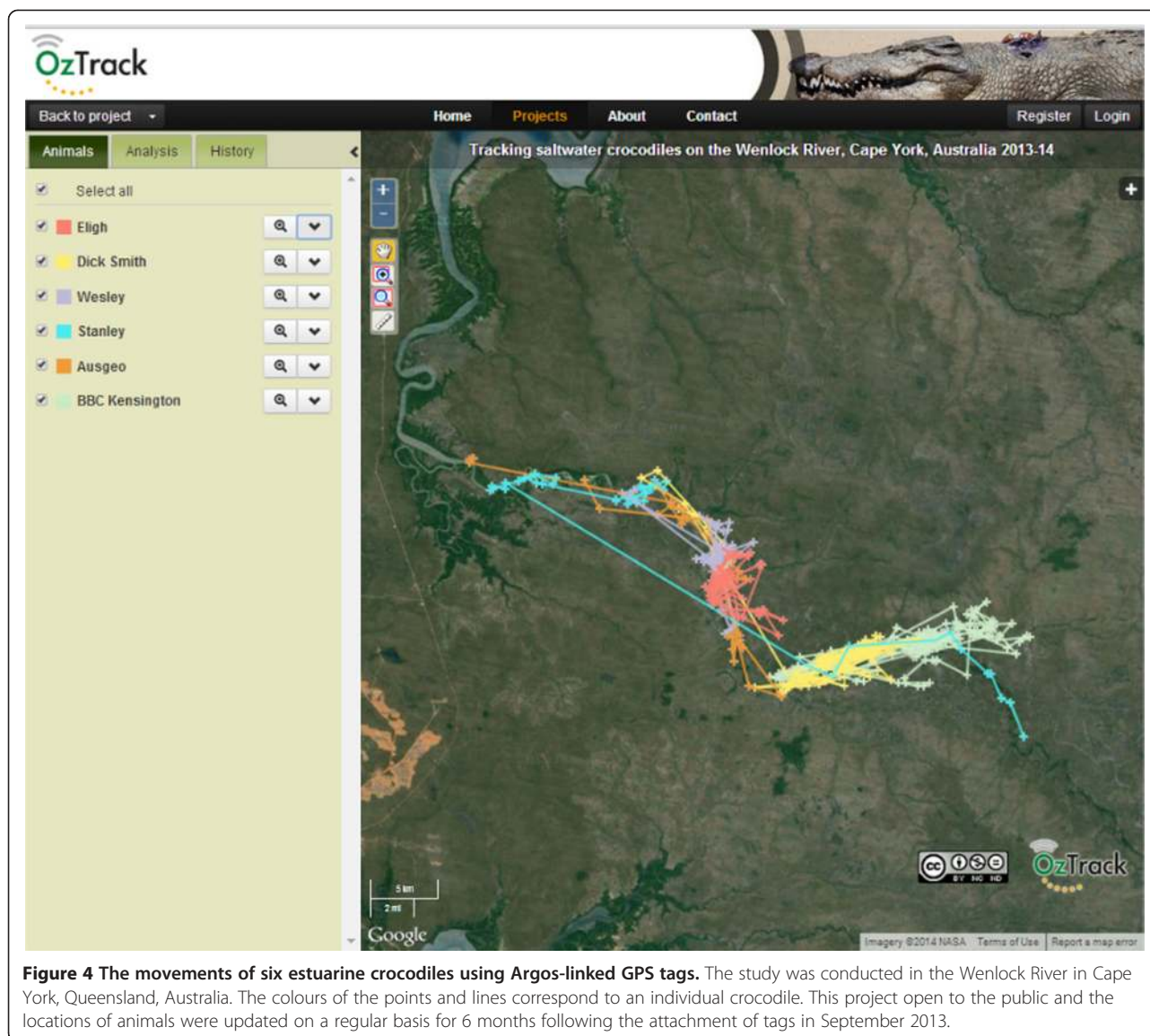
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Figure 3 The track of a rehabilitated southern cassowary following release into the Daintree National Park. The information in the left panel provides metrics on the number of detections (locations) for that animal, the start and end date of the tracking period and the length of the animal's trajectory. The track of animal "M2" contains 729 GPS locations gathered between 19/05/2011 and 13/09/2011.

improving connectivity of koala habitat. OzTrack was also employed to monitor the success of a rehabilitation and release scheme for southern cassowaries (*Casuarius casuarius*) [38]. OzTrack's configurable permission tool allowed the raw locations, movement metrics and home range estimates generated from GPS-tagged birds to be shared between project collaborators (Figure 3). Those collaborators working in the study area were also able to provide valuable insight into local disturbances that helped explain the timing and locality of observed movement behaviours. By facilitating data discussion and multi-user support, OzTrack helped elucidate behaviours which would have otherwise been difficult to interpret. Finally, between September 2013 and February 2014, OzTrack was used as both a research tool and as a

platform to promote public awareness towards estuarine crocodiles (*Crocodylus porosus*). Large crocodiles pose a significant risk to humans, and there are significant societal and political challenges in managing this potentially dangerous species [39]. To help raise public awareness regarding the habits of wild estuarine crocodiles, OzTrack was used to archive the movements of six adult crocodiles fitted with GPS transmitters (Figure 4). The project was open to the public to view the tracks in near real-time and apply a selection of analysis tools, and it was promoted via articles in the popular press and through public lectures. Promoting awareness through public outreach is necessary in order to explain science to the public and media; it is also a necessity to endorse fundraising activities, conservation measures and management decisions.

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Figure 4 The movements of six estuarine crocodiles using Argos-linked GPS tags. The study was conducted in the Wenlock River in Cape York, Queensland, Australia. The colours of the points and lines correspond to an individual crocodile. This project open to the public and the locations of animals were updated on a regular basis for 6 months following the attachment of tags in September 2013.

Open tools and software

By running a spatial DBMS within research cloud infrastructure, we achieved a scalable, persistent and secure data storage capability in which large tracking datasets can be managed in a structured and consistent manner [27]. The system is able to visualise tracks and extract movement metrics from datasets containing hundreds of thousands of animal locations. Dynamic upload capabilities with automated data recognition allow location data to be ingested into the DBMS with minimal pre-processing prior to upload, regardless of origin, time zone or geographical region. Integrating tools for spatial data visualisation (GeoServer) [32] and analysis (R) [34] combine the data archiving and processing components within a single online software platform [27]. As a result, location data can be edited, filtered, analysed and visualised with environmental and geopolitical layers without the need to convert and upload data files into separate software applications. This reduces the need for multiple copies of filtered and unfiltered datasets in numerous data formats (e. g. .TXT, .CSV and .SHP) and thus the potential for data duplication and error propagation.

To maximise software sustainability, the system was developed using exclusively open-source software components that ensure it can be open, interoperable, scalable and freely available. No additional software, add-on packages or plugins are required to run, visualise or export the raw, filtered or analysed data other than the Web browser (e.g. Internet Explorer, Firefox and Chrome). This approach offers some clear benefits over alternative applications which typically require a user fee or are dependent on downloading and installing commercial or non-commercial

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software. First of all, it is cost-effective, an important factor for smaller research bodies, consultancies and conservation organisations who have limited resources to dedicate towards software purchasing [40]. Second, the system is accessible from any computer or tablet with a Web browser. This benefits researchers who may work across multiple computers and devices and students or employees who may not have local administrative access on their computer. Third, the system provides a real-time collaborative environment where multiple users can access the same project. This is done via configurable permissions and access rights which are provided by the data owner to other OzTrack users through system's Web portal (Figure 1, [27]). This combination of free and open tools, infrastructure and a collaborative environment has been highlighted as key requirements to lead to more informed conclusions and management decisions [5,41].

Our trials with tertiary students illustrated the system's potential for teaching how biotelemetry can be a useful research tool in wildlife ecology and conservation. The main advantage over conventional methods was that once informed of the underlying theory, users were able to carry out standard procedures for analysing animal telemetry data without any "entrance barriers" [40], such as the requirement for students to be already proficient in a geographical information system (GIS) or have prior experience in using R. Many of the analysis and filtering tools implemented within the OzTrack system were modified from original functions contained within contributed R packages (Additional file 1: Table S1). Rather than R's command-line interface, the system provides an intuitive user interface that links to these functions though the Web portal. Users can access models, alter parameters, run analyses, visualise results and download data for post-processing without the need to develop or enter R code. Online help documentation and links to relevant publications are provided alongside each analysis or filtering tool as are tips for running models and providing reliable results. By integrating these tools within an accessible Web-based system, users can quickly understand how the choice of filter, model and parameter values influences estimates of animal movement and space use. Provided there is a thorough understanding of the statistical assumptions, we argue that by improving access to current tools in animal movement, research will encourage their uptake by the tracking community (particularly those inexperienced in R), thereby improving the quality and appropriateness of the analyses run.

The system's source code (including the underlying R code) has been released publically [33], providing users worldwide with the opportunity to verify, customise and rebuild the OzTrack system locally. This open approach to software is contrary to the "black-box" approach offered by many existing proprietary platforms, but is the same model adopted by Tagbase [42], and the R Programing Language [24] which sits at the core of OzTrack's analysis tools. An open system controlled, developed and managed by the global animal tracking community increases the potential for online facilities like OzTrack to evolve in parallel with advances in biotelemetry research. This scalability is vital for software long-term persistence, allowing for continual implementation and integration of new and powerful analysis tools, not only by a specific project or institution but also by the global biotelemetry community.

Open data

Registered users of OzTrack are able to create and describe new projects, upload datasets into specific projects, add users to projects and specify access controls and embargo periods. Once raw location data have been uploaded into a project, project owners can choose to embargo their data for a period of up to 3 years. While providing instantaneous access to telemetry datasets can be beneficial, this period was chosen because it provides adequate time for data owners to fulfil funding and publishing obligations before public access is granted. Data are protected under a number of Creative Commons Attributions Licence agreements, ranging from fully open access with no copyright [43], to strict limitations on usage [44]. Despite the increase in the number of data repositories holding tracking data, the vast majority of projects have not been made publicly available [13]. We consider a fixed embargo period with secure data licencing, and a digital object identifier (DOI) for released telemetry datasets, to be the optimum approach to inspire ecologists to move away from a research culture where data is proprietary, while installing measures to protect the intellectual property (IP) of the data owners.

To facilitate data discovery and re-use, open access is also promoted by sharing OzTrack metadata records (i.e. descriptions of the tracking dataset) via the ANDS-RDA portal [45]. RDA is an Internet-based data discovery service that describes the content, context, quality, structure and accessibility of distributed datasets, generated by researchers across Australia. OzTrack generates a metadata record for each project that is compliant with the RIF-CS metadata format. Each metadata record includes the project's title, description, study species, contributors, data licence and embargo period (if relevant) and links to the project's datasets on OzTrack. Metadata records are pushed to RDA via an automatic feed. Additional data regarding biological details (e.g. animal sex, age and body length), hardware specifications (e.g. telemetry device and location schedule) and deployment information (e.g. capture and release location, date and time of deployment and field personnel) may be uploaded in parallel with each location dataset. As telemetry devices have different sources and magnitudes of error [46], and animal

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behaviours can vary according to life history or habitat characteristics [9], providing complete and accurate metadata is critical to ensure that researchers not involved in the data collection process can properly account for accuracy and precision, detection probability and the species' ecology. In many cases, the data collected is not only valuable for the initial study objectives but also valuable for broader, longitudinal comparisons across studies, species, geographical range and years [47]. International projects such as the Starkey Project [48], OBIS-SEAMAP [24] and the European Roe Deer (EURODEER) project [26] illustrate the power of taking a collaborative and synthetic approach across species and localities. Furthermore, increased availability of raw data, and the error estimates for each location, also allow for better parameterizing and scrutinizing of Bayesian and mechanistic models (e.g. [49,50]). In these cases, increased sample size enables studies utilising these databases to generate predictive models that are more accurate, more reliable and enable stronger conclusions to be made. However, in order to ensure long-term accessibility and re-use of telemetry data, there is a need for a consensus with regard to best practise and data format standards between researchers, statisticians, tag manufacturers and database developers [15]. Only by creating global standards in data formats and metadata, will it be possible to guarantee compatibility and interoperability between telemetry databases, supporting truly synthetic and trans-disciplinary research.

Future directions

Testing throughout OzTrack's development highlighted several key areas of improvement [27]. A frequent suggestion from users was the implementation of additional R-based analysis and filtering tools, which have proved informative in the interpretation of animal movement data. While many of these tools were outside the initial scope of our project, the modular system design supports rapid development, implementation and integration within our system architecture [51]. An additional step to further facilitate the development of new tools may be to offer the R source code to users as an optional output, together with the raw and edited data, and model results (e.g. [8]). This increased transparency would also facilitate the development and implementation of new analysis tools by the wider biotelemetry community.

Another key feature requiring further work is the ability to enrich each location record with the relevant environmental and socio-economic information describing an animal's habitat. The OzTrack system currently holds 21 spatial layers describing climatological, environmental and political information (Additional file 1: Table S1) that with the current version of OzTrack can only be associated with locations on map overlays. Many of these layers are Australian-specific (due to our funding criteria), which

allowed us to be more specific on our supplied environmental, climatic and political spatial layers. None of these layers have a temporal component, representing mean-composites of environmental datasets over a particular time period with fixed political boundaries. Furthermore, there is currently no feature to allow users to upload vector- or raster-based spatial objects directly into the system. As animal location data is temporal in nature and animals respond to environmental cues which vary dynamically through time [9], it would be worthwhile incorporating spatial datasets at varying temporal resolutions (e.g. using the MODIS atmosphere, land, cryosphere or ocean data products [52]). OzTrack's Kalman filter tool (obtained from the ukfsst R package [53]), Movebank's Environmental-Data Automated Track Annotation (Env-DATA) software [54] and the RNCEP package for R [55] all offer this functionality. The system architecture was structured in a way to allow the animal locations to be linked with spatial datasets at varying temporal resolutions. This new functionality would allow the interactions between animals and their environment to be investigated at a much higher resolution, producing much more meaningful relationships.

Conclusions

New developments in tracking hardware, pressures for open access to data and the need for multidisciplinary collaborations are accelerating us towards a new age of ecological research [11]. The system infrastructure that we developed provides an integrated, online, free and open-source system that facilitates the uploading, editing, analysis, archiving and sharing of animal tracking datasets. The observed uptake by the Australasian biotelemetry community suggests that the system is proving a valuable resource for researchers despite the stipulation that the data must become publicly available once the embargo period has expired. While the OzTrack system is still in its infancy, our intent is that its framework will promote collaboration, encourage future tool development and help ensure the long-term legacy of animal location datasets. Platform sustainability into the future is however unsubstantiated, due to the short-term nature of funding cycles. Thus, the involvement of the community in terms of funding and system development, as well as integration of the platform into larger eScience infrastructures, may be required to ensure its longevity.

Availability of supporting data

The datasets supporting the results of this article are available in the OzTrack repository: tracking saltwater crocodiles on the Wenlock River, Cape York, Australia 2013–14 in http://oztrack.org/projects/125; tracking juvenile cassowaries on Cape Tribulation using GPS-based telemetry in https://oztrack.org/projects/2; and habitat restoration

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decisions based on koala movements in http://oztrack.org/
projects/40.

Additional files

Additional file 1: Table S1. Environmental, climatic and political layers
currently accessible in OzTrack.

Additional file 2: Table S2. Analysis and filtering tools implemented
into the OzTrack system with corresponding R packages.

Abbreviations

ANDS: Australian National Data Service; CSV: Comma-Separated Value;
DBMS: Database management system; DOI: Digital object identifier;
GIS: Geographical information system; IP: Intellectual property; IT: Information
technology; KML: Keyhole Markup Language; NeCTAR: National eResearch
Collaboration Tools and Resources; OBIS-SEAMAP: Ocean Biogeographic
Information System-Spatial Ecological Analysis of Megavertebrate Populations;
PNG: Portable Network Graphics; RIF-CS: Registry Interchange Format—
Collections and Services; RDA: Research Data Australia; SQL: Structured Query
Language; SRS: Spatial reference system; WGS: World Geodetic System;
XLS: Microsoft Excel file.

Authors' contributions

RGD prepared the manuscript, provided the statistical support and developed
the underlying R code. CB designed and implemented the spatial database
management system, Web Portal, GIS functionality and visualization services.
HAC and MW provided the vision and original concept for the OzTrack.org
project. All authors contributed to drafting the manuscript. The work was
carried out within the laboratories of CEF and JH. All authors read and
approved the final manuscript.

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