Department for Environment Food & Rural Affairs

DARWIN INITIATIVE

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Darwin Plus: Overseas Territories Environment and Climate Fund

Final Report

*To be completed with reference to the "Writing a Darwin Report" guidance: (http://www.darwininitiative.org.uk/resources-for-projects/reporting-forms). It is expected that this report will be a **maximum** of 20 pages in length, excluding annexes)*

Darwin Project Information

Project reference	DPLUS064
Project title	Characterising Bermuda's baitfish populations to improve management and fishery sustainability
Territory(ies)	Bermuda
Lead organisation	Bermuda Zoological Society
Partner institutions	Bermuda Government Department of Environment and Natural Resources, Bermuda Aquarium Museum and Zoo, Murdoch Marine, Bermuda Institute of Ocean Sciences
Grant value	£189,729
Start/end date of project	01 / April / 17 – 30 / Sept / 19
Project leader name	Joanna Pitt
Project website/Twitter/blog etc.	
Report author(s) and date	Joanna Pitt, Struan R Smith, Jirani Welch, Corey Eddy, Thaddeus Murdoch, Gretchen Goodbody-Gringley 31 / Jan / 20

1 Project Overview

Small bony fishes are of both ecological and economic importance, as they provide food for larger fishes and waterbirds, but are also exploited by commercial and recreational fishers for bait. In Bermuda, there are six species of so-called baitfishes, but the life history characteristics of these species were poorly understood. Baitfish landings from the commercial fishery peaked in the 1980s in conjunction with peak landings of reef fishes, but dropped off dramatically alongside them after the use of fish traps was banned in 1990. Compared to benchmarks from the early 1990s, reported catches of all baitfish groups have declined, although total landings have been fairly stable since approximately 2000. However, it was unclear whether these declines reflected declining baitfish populations or ongoing changes in fishing practices as more commercial fishers began targeting pelagic species rather than reef fishes. Prior to this project, there had been no fishery-independent evaluation of the relative abundance of these species, and no in-depth evaluation of the fisheries for them, but a number of stakeholders had expressed concern over the population status of at least some of these species. Currently, management of bait fishing restricts the size and type of nets that may be used, and prohibits net fishing in four inshore bays.

The Baitfish Management Plan 2015 identified a number of critical knowledge gaps, and noted that a greater understanding of the abundance, distribution, local life history characteristics and population genetics of these species could create opportunities for a wider range of management measures to be applied to these fishes. The goal of this project was to address those knowledge

gaps and facilitate the development of a revised management plan that would contribute to the sustainable management of baitfish populations. Understanding that successful management of marine resources requires input from those utilising the resource, the project also included interviews and surveys with commercial and recreational fishers in order to examine their bait fishing and bait use practices, including attitudes towards alternative baits, as well as their perceptions regarding the status of baitfish populations.

This project demonstrated that the six inshore baitfish species have variable annual cycles of abundance, and that baitfish presence and species richness are relatively consistent at some locations while being highly variable at others, although there was no obvious combination of environmental factors (i.e. temperature, depth or exposure) that could explain this variability. Importantly, the surveys found that the three smaller baitfish species are relatively abundant and widely distributed, with some preferences for particular types of inshore habitats. While one of the larger species, the Redear herring, is common, the other two large species were rarely found. Further, heterospecific shoaling behaviour puts juveniles of these larger species at risk of capture when the smaller species they are shoaling are targeted by fishers.

The three smaller baitfish species have low batch fecundity but extended reproductive seasons, and for two of these species, reproductively active individuals were found throughout the year. This has implications for the effectiveness of seasonal closures as a potential management measure. In contrast, the larger species appear to reproduce primarily in the spring and summer, based on the examination of gonads from the Redear herring and the timing of the appearance of small juveniles for the other two species, but no reproductively active adults of the two depleted species were found. These species should be considered data deficient.

The population genetics results demonstrated high levels of mixing within Bermuda baitfish populations, but a lack of connectivity with populations elsewhere in the region for all species other than the Redear herring. Baitfish management in Bermuda should therefore be precautionary, as replenishment from other populations is highly unlikely. However, there is no need to account for small scale genetic diversity locally.

Analysis of baitfish landings over time, together with fisher interviews and surveys, provided important insights into commercial and recreational bait fishing and bait use. Bait fishing was largely opportunistic and timed to precede primary fishing activities. Fishers' perceptions corroborated survey results indicating depletion and a deeper distribution of the Atlantic thread herring and Round sardinella. Concerns were also raised over the increasing prevalence of derelict vessels and large debris items, and the loss of seagrass habitats in association with the expanding presence of transitory juvenile green turtles. Although commercial fishers were familiar with the location of bays that are closed to net fishing, awareness was poor amongst recreational fishers and some poaching was observed, indicating a need for increased outreach regarding this important management measure.

This information facilitated the development of a new management plan for these species. The Baitfish Management Plan 2020 is now in final draft form (Annex 6_1) and ready to enter Bermuda's various marine stakeholder consultation processes. We anticipate that the finalisation and implementation of this plan will improve the sustainability of baitfish fisheries and help to ensure that these species continue to fulfil their key ecological role.

2 Project Stakeholders/Partners

The Marine Management team of the Bermuda Government Department of Environment and Natural Resources (DENR), of which project leader JP is a member, is a key stakeholder in this project, and was responsible for utilising information in the output reports to develop an improved management plan for baitfish in Bermuda – the primary outcome. DENR has supported this project from the proposal stage and provided office and lab space for key personnel and activities, as well as salary for JP and SRS. The Marine Resources Board (MRB), Bermuda's marine stakeholder consultation group, was consulted at the proposal stage and will provide input again as the first stage of consultation on the revised management plan that has been developed. The MRB's support for the project has been helpful in engaging support at the ministerial level.

Other key stakeholders are the commercial and recreational fishermen that utilise baitfishes to greater or lesser degrees to make their living and enjoy their hobby. Engaging with resource users is a key part of resource management, and vital to the successful introduction of alternative

management measures. In addition to providing data, the fisher surveys and interviews conducted as part of this project were a useful way to engage with these stakeholders. The interviews with commercial fishers who specialize in catching bait were particularly helpful and have contributed to an enhanced level of trust and collaboration between the Marine Resources Section and these individuals. We will engage with these stakeholders again in the coming months as we consult them regarding proposed changes to the way that baitfishes are managed.

The local science community and students were not explicitly defined as stakeholders in this project. However, the Bermuda Institute of Ocean Science (BIOS), where GGG is on the faculty, has a range of education programmes, and the intern that worked with GGG on the genetics study was supported by one of these programmes. Our local science contacts at both BIOS and the Bermuda Zoological Society (which hosts the funds) have resulted in 5 additional spin-off projects with local and visiting university students.

3 Project Achievements

3.1 Outputs

The primary outputs expected from this project were a series of reports on the **annual cycle in baitfish abundance** in Bermuda **(Output 1)**, **the broadscale distribution of these species** around the islands **(Output 4)**, **their life history characteristics (Output 2.1)** and **population genetics (Output 3),** as well as **an evaluation of the status and practices of the various bait fishing sectors (Output 5).** The topics of these reports cover aspects of biology and resource use that must be taken into account in order to successfully manage exploited fish populations and which were identified as knowledge gaps in the 2015 iteration of the Baitfish Management Plan. There was a lot of overlap in the background material and methodology associated with describing the annual cycle in baitfish abundance and the broadscale distribution of these species, so these two aspects of the project were combined in a single final report. The life history research originally planned to cover just the three smaller baitfish species, but was expanded to cover the Redear herring and also highlights some aspects of the life history of the other large baitfish species, which remain data deficient. The population genetics research also expanded to include all six of the key baitfish species. These reports have been completed and were provided to the Marine Resources Section of DENR to assist with the development of a revised management plan for baitfish species (the primary outcome specified for the project), which has now been completed. Summary versions of the three **output reports and the population genetics publication are attached** (Annexes 6_2, 6_4, 6_6 and 6_8). While the manuscripts for peer reviewed publications that will form secondary outputs (Output 2.2) are still being developed, the material was presented at the 72nd Gulf and Caribbean Fisheries Institute meeting in November of 2019, and copies of the **extended abstracts and poster are attached** (Annexes 6_3, 6_5, 6_7a and 6_7b). The extended abstracts will be available open access at www.gcfi.org in due course.

The ability of the DENR Marine Resources Section to develop a better management plan for Bermuda's baitfish species rested upon the provision of sufficient information on the biology and ecology of baitfish species, and the fisheries for them, in the output reports submitted by this project. The revised management plan is attached (see section 3.2 and Annex 6_1), and demonstrates that the work done through this project has addressed the major knowledge gaps identified in the previous plan. However, there were a few activities outlined in the original framework for this project that were not completed as originally envisaged.

As outlined in the 2018-19 annual report, otolith ageing for the three smaller study species (Activity 2.6) proved to be more difficult than anticipated, due to the size and structure of the otoliths from these extremely small-bodied fishes. Having worked with small otoliths before, the challenge presented by the otoliths from these particular species was not anticipated when evaluating the risk assumptions, where we expected acquiring sufficient samples to be the main risk factor. Despite significant time and effort testing different sectioning and staining methods, we were unable to develop a satisfactory protocol that would sufficiently expose the growth rings in enough of these otoliths to allow effective ageing of these fishes. Otolith samples for all six key baitfish species are still in hand however, and there is an action item in the revised management plan that addresses seeking partnerships with labs that

have a wider range of instrumentation available for analysing growth rings in such small fishes. It is hoped that these samples might form the basis for post-graduate study by project technician Jirani Welch. The main function of the otolith ageing data was to provide context for size at maturity and the annual reproductive cycles of these species, as well as their longevity. As it turns out, the fact that these species mature at such small sizes and reproduce essentially all year round means that this additional level of context, while scientifically very interesting, is not actually essential to adequately manage for continued reproduction in these species. The acquisition of at least some otoliths from the larger baitfish species as part of this component of the project means that we do have them on hand as we seek to further expand our knowledge of those species, which this project has identified as being depleted.

The loss of the temperature loggers purchased for this project (Activity 2.1) was also unfortunate. The sites used for monitoring the annual cycles in baitfish abundance were selected in part because of work conducted at some of them by other DENR personnel and by scientists from BIOS. This means that seawater temperature profiles for those sites, developed over 5 years, were available to provide context for the observations, and they could be interpreted in the context of the regular seawater temperature monitoring by the Bermuda Weather Service (www.weather.bm/climate).

Although the amount of **aerial and time lapse imagery (Output 6)** acquired through this project has been less than originally planned due to changes in methodology, the material acquired has been made available to other DENR personnel and has already proved useful for demonstrating the use of inshore habitats by juvenile and subadult sea turtles. The imagery is stored on an external hard drive but we are still in the process of developing appropriate curation documents so that it can be added to the library of the Bermuda Natural History Museum.

3.2 Outcome

The designated outcome of this project was the provision of relevant data to the DENR Marine Resources Section and the **development of a revised management plan for the six key baitfish species in Bermuda**. The Baitfish Management Plan 2020 is attached to this report in final draft form (Annex 6_1), and is ready to go through Bermuda's various marine stakeholder consultation processes. The development of this plan depended on the information on the biology and ecology of baitfish species, and the fisheries for them, provided in the output reports from this project. The 2015 version of the Baitfish Management Plan is also attached for comparison (Annex 6_10).

Associated with the development of this revised plan is the broader outcome of more **sustainable management of baitfish species in Bermuda**. The Marine Resources Section is anticipating some changes to the way that the commercial bait fishery is managed. It is hoped that building resilience at the base of the marine food web will enhance the ability of the broader marine ecosystem to withstand environmental perturbations, which are expected to increase under a changing climate. The multi-pronged approach of this project, which included fisher surveys and interviews as well as biological and ecological research, should mean that these changes are both practical and largely acceptable to the industry. Importantly, the data acquired through this project on the distribution and habitat preferences of baitfish species is very timely, as it will be included in the marine spatial planning process currently being undertaken as part of the Bermuda Ocean Prosperity Program (www.environment.bm/bermuda-ocean-prosperity). As such, it will inform the selection of areas that will form a network of marine reserves and **contribute to the overall conservation of important inshore habitats**. The concerns raised by many fishers regarding the prevalence of derelict vessels and large debris items, and their impact both on baitfish populations and the use of fishing nets, have provided added impetus to existing coastal cleanup efforts.

3.3 Long-term strategic outcome(s)

While **raising awareness** of the importance of baitfishes in Bermuda's coastal ecosystems, this project has **highlighted the importance of considering all components of the ecosystem** when managing the marine environment. It has also demonstrated how other,

apparently unrelated issues, such as the loss of sharks and the subsequent explosion of the green turtle population, can have cross-cutting impacts.

A side outcome of the fisheries evaluation component of this project is that the interactions between Marines Resources personnel and various fisheries stakeholders have enabled the section to build **stronger relationships with a number of commercial and recreational fishers**. These alliances will be important as the marine spatial planning process proceeds.

In addition, this project has **demonstrated the amount of data that can be collected with additional resources** and **how this information can then be used to drive informed decision-making.** It would not have been possible to acquire this information, and therefore develop the new management plan without the support of the grant. The achievements of this project can therefore be used to **encourage further investment in monitoring and data collection efforts** to inform environmental decision-making.

4 Sustainability and Legacy

This project was driven by concerns expressed across various stakeholder groups regarding the status of baitfish populations in Bermuda, and by the need for additional information that would enable the Marine Resources Section of DENR to develop a better management plan for these species. Those responsible for management of the resource defined the goals of the project to address specific knowledge gaps, and incorporating the input from fishers should mean that the proposed management changes will be largely acceptable to stakeholders. It is therefore anticipated that the broad stakeholder and political support for the project will continue through the implementation phase of the new management plan.

Most staff worked part time on this project as part of their primary jobs. Jirani Welch was the only person employed full time by the grant. Working on this project has added valuable post-degree experience to his resumé and helped him to get other grant-based contract work while he is seeking a permanent position. Two other Bermudian university students and a recent graduate (who is now employed in environmental health and safety) also gained valuable experience working on this project.

The laptop, microscope, scope cam, and various textbook resources remain the property of the Marine Resources Section and have enhanced our ability to complete future research of relevance to fisheries management in Bermuda. The underwater camera remains the property of the Bermuda Natural History Museum and will be used for future research projects. Samples of the various baitfish species were also added to the Museum collections.

5 Lessons learned

In smaller jurisdictions with predominantly small organisations, there is often a reliance on a small number of personnel, with few options for replacements. Contingency planning for unforeseen events that could affect key personnel is therefore a more important component of the risk assessment process in such situations than it might be elsewhere. We definitely learned this the hard way.

This project did require some changes in methodology in the first year. We had to replace the time-lapse camera monitoring of inshore baitfish schools with in-person visual surveys, as the images were not of sufficient quality to allow reliable discernment of baitfish schools under most weather conditions. The main limiting factor was finding a secure place for the cameras that was high enough, and yet close enough, to get a suitably angled view of the bays. This change also removed the need to use underwater cameras to occasionally validate the species composition of the schools. Although our initial plan was to use remote methods to save on personnel time and costs, the surveys generated more detailed data that fulfilled the primary goal of determining the annual cycles in the abundance and distribution of baitfish species. In addition, our presence in the field has provided the opportunity to connect with fishers and members of the public and talk to them about the project. The time lapse cameras were still used to monitor fishing activity, and the insertion of a piece of polarised film between the lens and the exposure housing has improved the quality of the images.

The survey results were uploaded using a specially designed google form, reducing analysis time to compensate for the additional field time. This has had the added benefit of facilitating instant sharing of data, making the monitoring of progress more efficient, and is an approach that we

would recommend to others. However, we would note that testing that the form adequately covers all aspects of data collection is an important step in making it useful.

Another lesson learnt was that while more data can lead to important insights (e.g. an understanding of the seasonal movements of the Bermuda anchovy, *A. choerostoma*,) it also creates analytical and presentation challenges, which lead to delays in the production of deliverables.

Shipping of preserved tissue for histology was more complicated than anticipated because of restrictions on the carriage of certain chemicals via air freight and the need to refill damp-shipped specimens on arrival. Ultimately, contractor WCE took drained samples as accompanied checked baggage, then refilled the containers on arrival before delivering the samples to the processing facility. This highlights some of the challenges of working in an isolated location.

The greatest challenge for this project arose from foreign exchange issues as a result of the fluctuating value of the British pound, since the grant period corresponded to a particularly volatile period for the GBP because of the EU exit process. This was exacerbated by the 11 week delay in the payment of the Q4 / in arrears payment for the first year of the project, such that we ended up $short on the funds spent. Even after careful budgeting in Year 2 to allow for a surplus that would allow us to cover this shortfall (with permission), funds still ended up $short on the final payment for the second year, again because of exchange rate issues. A partnership with a UK organisation as fiduciary would have perhaps alleviated this problem somewhat, but would necessarily have added another layer of overhead expense and made the proposal less competitive. Further, depending on a UK-based collaborating organisation restricts the ability of UKOTs to drive their own conservation and environmental management agenda if suitable partners cannot be found.

We are grateful for the support of LTSI staff in their role as the grant managers. It has been very helpful to have a name and an email address, with experienced personnel at the other end, for rapid communication and advice. This approach to grant management is both more flexible and less intimidating for smaller organisations as compared to dealing with a large, faceless funding agency, and it is much appreciated.

5.1 Monitoring and evaluation

Regular meetings between project personnel were needed at the start of the project, as we were testing the methods and then revising them. Per the 2017 change request, the major methodology change was replacing time lapse cameras with in person visual surveys as the main way of evaluating baitfish presence in the monitoring bays over the course of the year. Meetings then became more opportunistic, taking place over the physical exchange of samples or via email discussions. The use of a Google form and Google sheets for data management and basic manipulation facilitated the instant sharing of data, which in turn made monitoring progress easier and less time-consuming. Our original approach was based on making one person responsible for keeping track of progress in order to avoid confusion, but online access to the data meant that everyone could keep track at the same time, reducing the burden of monitoring. Project leader JP kept other Marine Resources staff updated on the progress of the project at section staff meetings, and commercial fishers were updated via notices in the quarterly Fisheries Newsletter.

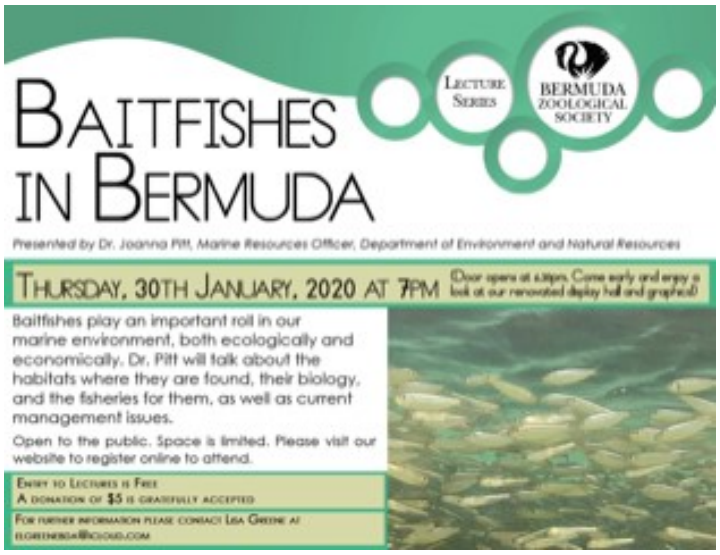
Presenting the research results at the regional Gulf and Caribbean Fisheries Institute meeting allowed us to get input from other scientists, which was particularly useful for the reproductive work. This was how we learned that certain aspects of the gonad histology showed that *Hypoatherina harringtonensis* was a benthic spawner.

5.2 Actions taken in response to annual report reviews

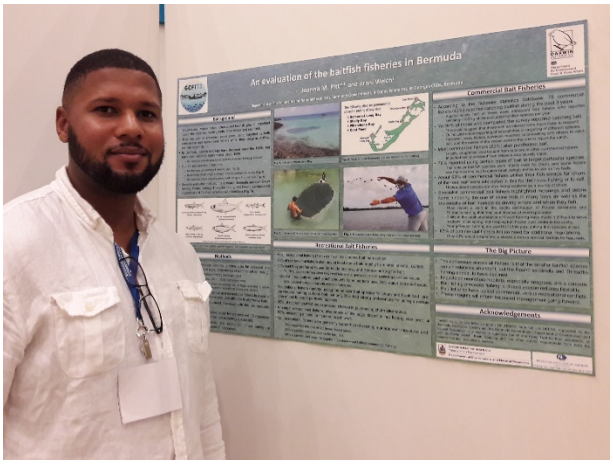
6 Darwin Identity

Darwin Plus / DEFRA has been recognised as the lead funder for the Bermuda Baitfish project in all written and oral communications regarding this work. Locally, the project was announced in the Fisheries Newsletter in January 2017, and a longer article was included in the winter 2018-19 issue that included the mail survey for commercial fishers (see Annex 6_11). During 2018-19, there were two short outreach articles in local outreach newsletters (see Annex 6_12 and

http://bios.edu/currents/looking-out-for-the-little-guys/) where this support was mentioned in the text. The final results of the different strands of research were presented in a public lecture hosted by BZS / BAMZ on January 30, 2020 (see below), with Darwin Plus / DEFRA logos featured on the opening and closing slides and also credited verbally.



Darwin Plus / Defra are acknowledged in the funding section of the genetics paper that was published open access with PeerJ (see Annex 6_8), and the Darwin logo was included on the poster when this work was presented at the Gulf and Caribbean Fisheries Institute (GCFI) meeting in 2018. The remainder of the work was presented at GCFI in 2019, in two oral presentations, given by JP and JW, and a poster (see Annex 6_7a and photo below). The Darwin and DEFRA logos were featured on the opening and closing slides of both presentations and in the upper right corner of the poster. The Darwin Plus funding leads the acknowledgements sections in all three extended abstracts submitted to the conference proceedings (see Annexes 6_3, 6_5 and 6_7b), which will be available online in due course. GCFI is well attended by fisheries and environmental managers from around the region, including those from other UKOTs.



Jirani Welch at GCFI 72 in Punta Cana, Dominican Republic, November 2019

As this is Bermuda's second major DPLUS grant, most people engaged in environmental work locally are aware of the program. Awareness is high amongst DENR and BAMZ / BZS staff and associates, BIOS scientists, members of the Marine Resources Board, and anyone who was associated with the lionfish work (DPLUS001) undertaken previously. This project has been promoted to members of the general public with environmental interests who receive DENR's Envirotalk newsletter. The presentation on January 30 in association with BZS / BAMZ reached more than 60 additional members of the public with an interest in environmental issues.

Further press releases and public presentations of the project results are anticipated as part of the public consultation process for the revised management plan, and the critical role of the DPLUS funding will be duly acknowledged.

7 Finance and administration

7.1 Project expenditure

Project spend (indicative) since last annual report	2019/20 Grant (£)	2019/20 Total actual Darwin Costs (£)	Variance %	Comments (please explain significant variances)
Staff costs				
Consultancy costs				
Overhead Costs (includes audit)				
Travel and subsistence				
Operating Costs				
Capital items				
Others				
TOTAL				

Staff employed (Name and position)	Cost (£)
TOTAL	

Consultancy – description and breakdown of costs	Other items – cost (£)
TOTAL	

Capital items – description	Capital items – cost (£)
TOTAL	

Other items – description	Other items – cost (£)
Publication costs – Memberships for team to PeerJ ($1995)	
TOTAL	

Exchange rate wascalculated at $1.29 per £1, which represents the average exchange rate received on incoming payments over the course of the project.

7.2 Additional funds or in-kind contributions secured

Source of funding for project lifetime	Total (£)
DENR / BAMZ salaries for JP and SRS	
BAMZ accounting service support	
Use of DENR Marine Resources lab equipment etc. (in kind)	

Consumables provided by DENR Marine Resources	
Use of OHMS mailing for surveys (in kind)	
Use of Fisheries vessels for broadscale survey – 2 days (in kind)	
BIOS support of GGG salary	
BIOS overhead reduction	
NSF REU studentship for ES	
BZS summer internship (KB) ADDITIONAL	
Bermuda Government Summer Employment Program (JB) ADDITIONAL	
TOTAL	

*Note that £15,600 worth of boat use that was to be provided in kind by BAMZ was not utilized due to changes in collecting methodology.

Source of funding for additional work after project lifetime	**Total (£)**
TOTAL	

7.3 Value for Money

Overall value for money

This project provided value for money by leveraging experienced, salaried Bermuda Government / BAMZ personnel to supervise work completed by an entry level technician, an intern and two independent contractors. BZS, as host organisation, has a strong summer internship program and this was leveraged in a manner that provided additional support to the project while also providing valuable experience to a recent university graduate and an EU graduate student. The Bermuda Government's Summer Employment Program provides opportunities for university students to intern with Government departments, and was leveraged in a similar manner. Working with a project partner at BIOS also provided the opportunity to leverage the NSF-funded REU internship program, a highly competitive program that provides research opportunities to top-tier final year undergraduate students from the U.S.

Challenges and opportunities in providing value for money for projects in the UKOTs

Most of the UKOTs are small, relatively remote islands with small populations. In locations like this, there are limited opportunities for local production of food or consumer goods. Further, electricity is generally very expensive because of the size of the customer base relative to the infrastructure required and the need to import fuel. In Bermuda, everything bar the approximately 10% of food requirements that can be produced locally must be shipped in from ports that are at least 1,500 km away. This affects both price and the efficiency of the supply chain. The limited customer base also affects the availability and cost of other services in that there is often only one provider of a given service, and prices are higher than in larger jurisdictions in order to compensate for the lower volume of work. Further, if a sole service provider is out of commission due to equipment issues or for personal reasons, this can cause delays that impact efficiency and possibly also cost. These factors combine to raise the cost of living in Bermuda to amongst the highest in the world, making it a very expensive jurisdiction in which to operate. In addition, the unique biogeographical situation of Bermuda and certain other UKOTs means that, for a novel project, there are often no models from other locations that are similar enough to use as a guide, and information or methods from elsewhere may not be applied as readily as expected in the local context. This can reduce the efficiency of project implementation. It is therefore difficult to deliver value for money in Bermuda and similar UKOTs when compared to the UK, Europe or larger developing countries.

However, the small size of many UKOTs also provides opportunities to increase the efficiency and effectiveness of field work, which was demonstrated during the broadscale survey

component of this project when we found that it was possible to exceed our target survey area. Small communities also provide opportunities for effective surveys and outreach efforts, as many of the stakeholders are known either personally or through existing networks. Utilising such connections, we easily contacted the specialist bait fishers and managed to increase participation in the survey of other commercial fishers when the initial response via mail was lower than we had hoped.

Annex 1 Project's full current logframe as presented in the application form (unless changes have been agreed)

Please insert your project's logframe (if your project has a logframe), including indicators, means of verification and assumptions. N.B. if your application's logframe is presented in a different format in your application, please transpose into the below template. Please feel free to contact Darwin-Projects@ltsi.co.uk if you have any questions regarding this.

Project summary	Measurable Indicators	Means of verification	Important Assumptions
Impact: This project will describe the life history, genetics, abundance and distribution of Bermuda's baitfishes, and the fishery for them, facilitating more sustainable management of these economically and ecologically important species.			
Outcome: Information on the genetics, life history, abundance and distribution of Bermuda's baitfish species, and the fishery for them, will be provided to DENR for incorporation into an improved management plan.	0.1 Five reports / publications completed and provided to DENR's Marine Management Team. 0.2 Using information in the reports / publications, the project leader will work with senior DENR staff to develop a draft of a revised baitfish management plan by December 2019, to go to consultation by January 2020.	0.1 Reports provided to DENR and made available at www.environment.bm 0.2 Draft baitfish management plan presented to the Marine Resources Board and Commercial Fisheries Council, and available at www.environment.bm	Publication schedules do not delay completion of reports or availability of scientific paper
Outputs: **1**. Report describing the annual cycle of baitfish populations	1.1 Report completed	1.1 Report provided to DENR	Baitfish can be identified to species from underwater images. Mitigation: Samples will help to confirm species ID. Weather does not interfere with cameras or compromise images for any extended period.
2. Report and scientific publication describing the age, growth and reproduction of Bermuda anchovy, reef silverside, and dwarf herring, with management suggestions	2.1 Report completed 2.2 Scientific publication	2.1 Report provided to DENR 2.2 Publication in press or available online	Adequate numbers of each species available for sampling throughout the year. Publication schedules do not delay completion of reports or availability of scientific paper

3. Population genetics analysis of 3 small-bodied baitfish species published and sequences uploaded to publicly available databases.	3.1 Advisory report completed 3.2 Scientific publication 3.3 Sequences uploaded	3.1 Report provided to DENR 3.2 Publication in press or available online 3.3 Sequences available online	Publication schedules do not delay completion of reports or availability of scientific paper
4. Report describing broadscale survey of peak baitfish abundance / distribution	4.1 Report provided to DENR	4.1 Report provided to DENR	
5. Report on baitfishing, bait use and fisher perceptions, with management suggestions	5.1 Report provided to DENR	5.1 Report provided to DENR	Commercial and recreational fishers will co-operate and provide information and opinions during interviews and surveys.
6. All imagery curated and stored at BAMZ library for other researchers to access upon request	6.1 Images provided to BAMZ library	6.1 Images provided to BAMZ library on external storage media	

Activities (each activity is numbered according to the output that it will contribute towards, for example 1.1, 1.2 and 1.3 are contributing to Output 1)

1.1 - Use time-lapse cameras to monitor fishing activity in two bays that are open to fishing and poaching in two bays where net fishing is prohibited.

1.2 Install in-water temperature loggers at the same 4 bays. Retrieve data quarterly. Download, describe and compare annual temperature cycles across bays.

1.345 - Activities 1.3, 1.4 and 1.5 in the original logframe were replaced by visual surveys of baitfish school presence in two bays that are open to fishing and four bays where net fishing is prohibited, with observers recording information on size, species composition and size structure.

1.6 Identify the time of peak baitfish abundance to optimise the broadscale survey in year 2.

1.7 Complete report describing the annual cycle of baitfish abundance, comparing species, locations and temperature.

2.1 Sample baitfishes at a variety of locations on a weekly basis in year 1, and twice a month in year 2. Ensure that monitored bays are included in the sampling locations at least once per month.

2.2 / 3.1 During initial processing, take tissue samples for genetics analysis from 40 individuals of Bermuda anchovy, *Anchoa choerostoma*, reef silverside, *Hypoatherina harringtonensis*, and dwarf herring, *Jenkinsia lamprotaenia*, ensuring that each species is represented by samples from the widest possible range of locations.

2.3 Measure (total length) and weigh at least 10 individuals from each 1cm size class present for each of Bermuda anchovy, reef silverside, and dwarf herring from each sample.

2.4 Dissect specimens to remove gonads and otoliths. Stage gonads visually. Preserve at least 20 mature ovaries from each species each month for histology.

2.5 Evaluate batch fecundity for up to 20 ripe ovaries per month, as available.

2.6 Prepare and read daily growth rings from at least 10 individuals from each 1cm size class present for each of Bermuda anchovy, reef silverside, and dwarf herring for each month. Calculate growth rates and back-calculate spawning dates.

2.7 Have monthly ovary samples processed for histological analysis and read slides to evaluate spawning condition.

2.8 Write report on the age, growth and reproductive characteristics of Bermuda anchovy, reef silverside, and dwarf herring, including an assessment of the evidence for temperature-dependent sex-determination in the reef silverside. Include potential management measures based on these characteristics.
2.9 Present results at an international conference and prepare scientific publication(s).

3.1 (See sampling note above, in 2.2)
3.2 Extract DNA with Qiagen Extraction Kit, amplify via PCR, and sequence using single pass Sanger sequencing (Beckman Coulter Genomics).
3.3 Use Sequencher5.4 to align and edit sequence results, and analyse using standard population genetic approaches (Fst, Φst, AMOVA).
3.4 Write advisory report for DENR and scientific publication on genetic diversity and rates of connectivity of Bermuda anchovy, reef silverside, and dwarf herring. Present results at an international conference.
3.5 Upload sequences to publicly available databases: the NCBI database, GenBank, and the barcoding of life data systems database, BOLD.

4.1 Test drone flyover technique for baitfish school detection and area calibration.
4.2 Survey 50-60 sites over 10 days during the period of peak baitfish abundance, as identified in Activity 1.6.
4.3 Select and analyse 300 aerial images for presence and spatial extent of baitfish schools.
4.4 Use surface and in-water visual surveys (not underwater cameras as initially planned) to assess species composition and density of baitfish schools.
4.5 Prepare report on the abundance and distribution of baitfish around Bermuda.

5.1 Develop survey instrument for commercial fishers to examine bait fishing and bait use practices, and attitudes towards alternative baits. Mail survey out to all commercial fishers.
5.2 Develop questions and conduct semi-structured interviews with specialised bait fishers.
5.3 Develop survey instrument and conduct roving, opportunistic in-person surveys of at least 25 recreational fishers engaging in bait fishing.
5.4 Analyse and summarise results and prepare report, including any potential management measures suggested by the results.

6.1 Assemble all images on external storage media
6.2 Catalogue media and metadata in BAMZ library

Annex 2 Report of progress and achievements against final project logframe for the life of the project (<u>if your project has a logframe)</u>

Project summary	Measurable Indicators	Progress and Achievements for the life of the project
Impact: This project will describe the life history, genetics, abundance and distribution of Bermuda's baitfishes, and the fishery for them, facilitating more sustainable management of these economically and ecologically important species.		The research done through this project has generated sufficient data to facilitate the development of a revised management for baitfish species in Bermuda. This new management plan is based on a large amount of newly acquired biological, ecological and socio-economic information, to the extent that fisheries managers believe that it will be acceptable to stakeholders and facilitate improved and more sustainable management of baitfish species.
Outcome Information on the genetics, life history, abundance and distribution of Bermuda's baitfish species, and the fishery for them, will be provided to DENR for incorporation into an improved management plan.	0.1 Five reports / publications completed and provided to DENR's Marine Management Team. 0.2 Using information in the reports / publications, the project leader will work with senior DENR staff to develop a draft of a revised baitfish management plan by December 2019, to go to consultation by January 2020.	0.1 Outputs 1 and 3 were combined into a single report. Therefore 3 reports and a publication covering the five threads of this project have been provided to the Marine Resources Section of DENR. (See Annexes 6_2, 6_4, 6_6 and 6_8) 0.2 The Baitfish Management Plan 2020 has been developed (Annex 6_1)and is ready to begin the stakeholder consultation process.
Output 1. Report describing the annual cycle of baitfish populations	1.1 Report completed and provided to DENR	Outputs 1 and 3 were combined into a single report presented to DENR. See Annex 6_2 for the summary. An extended abstract for the conference presentation on this work is attached in Annex 6_3 and will be available online in due course.
Activity 1.1 - Use time-lapse cameras to monitor fishing activity in two bays that are open to fishing and poaching in two bays where net fishing is prohibited.		The time lapse cameras were redeployed to monitor fishing activity. During the period up to March 31st, 2019, this approach detected 87 separate instances of net fishing activity across two study bays that are open to fishing, and one instance of poaching a bay that is closed to fishing.
Activity 1.2 - Install in-water temperature loggers at primary study bays. Retrieve data quarterly. Download, describe and compare annual temperature cycles across bays.		Temperature loggers were deployed in the spring of 2018, but were lost during storm activity. Temperature climatology data from other sources were used in combination with Bermuda Weather Service data to provide context for this work.

Project summary	Measurable Indicators	Progress and Achievements for the life of the project
Activity 1.345 - Activities 1.3, 1.4 and 1.5 in the original logframe were replaced by visual surveys of baitfish school presence, including information on size, species composition and size structure.		More than 900 visual surveys were conducted in total, and the primary monitoring sites (two bays closed to net fishing and two bays where fishing is permitted) were surveyed at least weekly.
Activity 1.6 – Identify the period of peak baitfish abundance to help plan a broadscale drone survey of abundance and distribution.		Based on observations, the period of peak abundance was identified as occurring between July and October, with densest “bait balls” appearing from late August onwards.
Activity 1.7 – Prepare Report		The report for this component was combined with the report for Output 3. A summary version is attached (Annex 6_2).
Output 2. Report and scientific publication describing the age, growth and reproduction of Bermuda anchovy, reef silverside, and dwarf herring, with management suggestions	2.1 Report completed and provided to DENR 2.2 Scientific publication	The report on this component of the project is complete and has been provided to DENR. A summary version is attached (Annex 6_4). A manuscript for scientific publication is being prepared. The extended abstract for the conference presentation on this work is attached (Annex 6_5) and will be available online in due course.
Activity 2.1 - Sample baitfishes at a variety of locations on a weekly basis. Ensure that monitored bays are included in the sampling locations at least once per month		Sampling took place weekly through March of 2019, with sufficient coverage of the regular monitoring sites.
Activities 2.2 - 2.4 Measure (total length) and weigh at least 10 individuals from each 1cm size class present for each of Bermuda anchovy, reef silverside, and dwarf herring from each sample. Dissect specimens to remove gonads and otoliths. Stage gonads visually. Preserve at least 20 mature ovaries from each species each month for histology.		More than 6,800 fish across all species were measured, weighed and dissected, with otoliths extracted and more than 700 gonads preserved for histology and batch fecundity.
Activity 2.5 - Evaluate batch fecundity for up to 20 ripe ovaries per month, as available.		Average batch fecundity for these species was calculated based on at least 20 ripe ovaries. Fecundity varied more with size than expected, so assessing monthly variations in fecundity was not deemed worthwhile.
Activity 2.6 - Prepare and read daily growth rings from at least 10 individuals from each 1cm size class present for each of Bermuda anchovy, Reef silverside, and Dwarf herring for each month. Calculate growth rates and back-calculate spawning dates.		Otolith processing did not progress as anticipated. The instrumentation we had was insufficient for dealing with the small size of these otoliths. Samples have been retained for future work in partnership with a lab that has more advanced technology.
Activity 2.7 - Have monthly ovary samples processed for histological analysis and read slides to evaluate spawning condition.		585 ovary samples were processed for histology, the slides were interpreted and the data represented graphically.
Activity 2.8 - Write report on the age, growth and reproductive characteristics of Bermuda anchovy, Reef silverside, and Dwarf herring, including an assessment of		This report is complete and has been presented to DENR. A summary version is attached (Annex 6_4).

Project summary	Measurable Indicators	Progress and Achievements for the life of the project
the evidence for temperature-dependent sex-determination in the reef silverside. Include potential management measures based on these characteristics.		
2.9 Present results at an international conference and prepare scientific publication(s).		The results were presented at the 72nd meeting of the Gulf and Caribbean Fisheries Institute in November of 2019. See attached extended abstract (Annex 6_5). A manuscript is being prepared for scientific publication.
Output 3. Population genetics analysis of 3 small-bodied baitfish species published and sequences uploaded to publicly available databases.	3.1 Advisory report completed 3.2 Scientific publication 3.3 Sequences uploaded	The results of this work were provided to DENR and published in the online journal PeerJ in 2019 (see Annex 6_8). Sequences of Bermuda's baitfish species have been uploaded to Genbank (Accession numbers MK871561 to MK871655). https://www.ncbi.nlm.nih.gov/genbank/
Activities 3.1-3.4 – Genetics lab work, advisory report for DENR and scientific publication on genetic diversity and rates of connectivity of Bermuda anchovy, reef silverside, and dwarf herring. Present results at an international conference.		Budget transfers in 2017-18 allowed the inclusion of samples from all six local inshore baitfish species in this analysis and GGG performed some additional comparative work during 2-18-19. DENR received a summary of the findings and this work was published in the online journal PeerJ in 2019 (see Annex 6_8). The results were presented at the 71st meeting of the Gulf and Caribbean Fisheries Institute in November of 2018 (see Annex 6_9)
Activity 3.5 - Upload sequences to publically available databases: the NCBI database, GenBank, and the barcoding of life data systems database, BOLD.		Sequences have been uploaded to Genbank (Accession numbers MK871561 to MK871655). https://www.ncbi.nlm.nih.gov/genbank/
Output 4. Report describing broadscale survey of peak baitfish abundance / distribution	4.1 Report provided to DENR	Outputs 1 and 3 were combined into a single report presented to DENR. See Annex 6_2 for the summary. An extended abstract for the conference presentation on this work is attached in Annex 6_3 and will be available online in due course.
Activity 4.1. Test drone flyover technique for baitfish school detection and area calibration.		The aerial drone was able to distinguish denser schools in clear water over sandy bottoms, but had trouble detecting sparsely schooled fish over more mottled benthos.
Activity 4.2 Survey 50-60 sites over 10 days during the period of peak baitfish abundance, as identified in Activity 1.6. Activity 4.3 Select and analyse 300 aerial images for presence and spatial extent of baitfish schools. Activity 4.4 Use surface and in-water visual surveys (not underwater cameras as initially planned) to assess species composition and density of baitfish schools.		95 km of inshore coastline, including over 150 bays, were surveyed using a combination of drone photography and visual surveys, validated by in-water visual surveys and cast net sampling. Large swaths were covered in a single day to get a realistic overview of baitfish presence / absence, relative abundance and species composition, while avoiding confounding by meso-scale movements between surveys. Data were entered into mapping software.

Project summary	Measurable Indicators	Progress and Achievements for the life of the project
Activity 4.5 Prepare report on the abundance and distribution of baitfish around Bermuda.		The report for this component was combined with the report for Output 1 and presented to DENR. A summary version is attached (Annex 6_2)
Output 5. Report on baitfishing, bait use and fisher perceptions, with management suggestions	5.1 Report provided to DENR	The report on this component of the project is complete and has been provided to DENR. A summary version is attached (Annex 6_6). The extended abstract for the conference presentation on this work is attached (Annex 6_7b) and will be available online in due course.
5.1 Develop survey instrument for commercial fishers to examine bait fishing and bait use practices, and attitudes towards alternative baits. Mail survey out to all commercial fishers.		Surveys were mailed out to all commercial fishing vessel owners and 18 responses were received (11% of non-specialist commercial fishers).
5.2 Develop questions and conduct semi-structured interviews with specialised bait fishers.		In-depth interviews were conducted with the 2 specialist bait fishers, and one former specialist.
5.3 Develop survey instrument and conduct roving, opportunistic in-person surveys of at least 25 recreational fishers engaging in bait fishing.		41 surveys were conducted in total – 11 through the online vehicle and 30 in person. All data were entered into the SurveyMonkey platform for analysis (Annex 5). The two approaches gave us a greater diversity of participants.
5.4 Analyse and summarise results and prepare report, including any potential management measures suggested by the results.		The report on this component of the project is complete and has been provided to DENR. A summary version is attached (Annex 6_6).
Output 6. All imagery curated and stored at BAMZ Natural History Museum for other researchers to access upon request	6.1 Images provided to BAMZ	The images are available on an external hard drive by use for other researchers and managers, but catalogues and metadata are still being compiled to enable proper accession to the BAMZ library.
6.1 Assemble all images on external storage media 6.2 Catalogue media and metadata in BAMZ library		The amount of imagery acquired through this project has been less than originally planned due to changes in methodology. The material acquired has already been made available to other DENR personnel. The imagery is stored on an external hard drive but we are still in the process of developing appropriate curation documents so that it can be added to the library of the Bermuda Natural History Museum.

Annex 3 Standard Measures

Code	Description	Totals (plus additional detail as required)
Training Measures		
1	Number of (i) students from the UKOTs; and (ii) other students to receive training (including PhD, masters and other training and receiving a qualification or certificate)	-
2	Number of (i) people in UKOTs; and (ii) other people receiving other forms of long-term (>1yr) training not leading to formal qualification	-
3a	Number of (i) people in UKOTs; and (ii) other people receiving other forms of short-term education/training (i.e. not categories 1-5 above)	i) 1 internship from D+ funds (ND) 1 Bermuda Government funded internship (JB) 1 BZS funded internship (KB) ii) 1 BIOS / US NSF funded internship (ES) 1 EU ERASMUS funded internship (JN)
3b	Number of training weeks (i) in UKOTs; (ii) outside UKOTs not leading to formal qualification	i) 10 weeks (ND) 10 weeks (JB) 8 weeks (KB) ii) 15 weeks (ES) 12 weeks (JN)
4	Number of types of training materials produced. Were these materials made available for use by UKOTs?	-
5	Number of UKOT citizens who have increased capacity to manage natural resources as a result of the project	1 (JW via on the job training)
Research Measures		
9	Number of species/habitat management plans/ strategies (or action plans) produced for/by Governments, public authorities or other implementing agencies in the UKOTs	1 draft management plan covering 6 species of baitfishes
10	Number of formal documents produced to assist work in UKOTs related to species identification, classification and recording.	-
11a	Number of papers published or accepted for publication in peer reviewed journals written by (i) UKOT authors; and (ii) other authors	1 paper published (2 UKOT authors and 1 other author) (Further publications anticipated.)

Code	Description	Totals (plus additional detail as required)
11b	Number of papers published or accepted for publication elsewhere written by (i) UKOT authors; and (ii) other authors	3 extended abstracts in GCFI conference proceedings (jointly between 4 UKOT authors and 1 other author)
12b	Number of computer-based databases enhanced (containing species/genetic information). Were these databases made available for use by UKOTs?	1 (COI sequences for Bermuda populations of the 6 study species uploaded to public database NCBI Genbank – accession numbers
13a	Number of species reference collections established. Were these collections handed over to UKOTs?	-
13b	Number of species reference collections enhanced. Were these collections handed over to UKOTs?	-
Dissemination Measures		
14a	Number of conferences/seminars/workshops/stakeholder meetings organised to present/disseminate findings from UKOT's Darwin project work	1 public presentation held at BAMZ on 30 / Jan / 20 2 presentations to Government Boards – the Marine Resources Board and the Commercial Fisheries Council – will take place in March 2020 Additional stakeholder meetings will take place later in the consultation phase
14b	Number of conferences/seminars/ workshops/stakeholder meetings attended at which findings from the Darwin Plus project work will be presented/ disseminated	2 conferences attended: 2 talks and 2 posters presented.
Physical Measures		
20	Estimated value (£s) of physical assets handed over to UKOT(s)	£ laptop, dissecting microscope, microscope camera, underwater camera, text books
21	Number of permanent educational/training/research facilities or organisation established in UKOTs	-
22	Number of permanent field plots established in UKOTs	-
23	Value of resources raised from other sources (e.g., in addition to Darwin funding) for project work	£

Annex 4 Publications

Type * (e.g. journals, manual, CDs)	Detail (title, author, year)	Nationality of lead author	Nationality of institution of lead author	Gender of lead author	Publishers (name, city)	Available from (e.g. weblink, contact address, annex etc)
Journal article*	Goodbody-Gringley G, Strand E, Pitt JM. 2019 Molecular characterization of nearshore baitfish populations in Bermuda to inform management.	Bermudian / US	Bermuda / US	female	PeerJ - https://peerj.com/	https://peerj.com/articles/7244/
Genetic sequences (COI gene) for all 6 study species	Goodbody-Gringley G, Strand E, Pitt JM. 2019	Bermudian / US	Bermuda / US	female	NCBI Genbank	https://www.ncbi.nlm.nih.gov/genbank/ Accession numbers MK871561 to MK871655.
Outreach newsletter article					BIOS Currents	http://bios.edu/currents/looking-out-for-the-little-guys/

Annex 5 Darwin Contacts

Ref No	DPLUS064
Project Title	Characterising Bermuda's baitfish populations to improve management and fishery sustainability
Project Leader Details	
Name	Joanna Pitt
Role within Darwin Project	Project leader
Address	
Phone	
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Partner 1	
Name	Struan R Smith
Organisation	Bermuda Aquarium Museum and Zoo
Role within Darwin Project	Project manager
Address	
Skype	
Email	
Partner 2	
Name	Thaddeus Murdoch
Organisation	Murdoch Marine
Role within Darwin Project	Data collection, analysis and mapping
Address	
Skype	
Email	
Partner 3	
Name	Gretchen Goodbody-Gringley
Organisation	BIOS, now at CCMI
Role within Darwin Project	Leader of genetics study
Address	
Skype	
Email	

Annex 6 Supplementary material (optional but encouraged as evidence of project achievement)

checklist for submission

	Check
Is the report less than 10MB? If so, please email to Darwin-Projects@ltsi.co.uk putting the project number in the Subject line.	✓
Is your report more than 10MB? If so, please discuss with Darwin-Projects@ltsi.co.uk about the best way to deliver the report, putting the project number in the Subject line.	
Have you included means of verification? You need not submit every project document, but the main outputs and a selection of the others would strengthen the report.	✓
Do you have hard copies of material you want to submit with the report? If so, please make this clear in the covering email and ensure all material is marked with the project number. However, we would expect that most material will now be electronic.	N/A
Have you involved your partners in preparation of the report and named the main contributors	✓
Have you completed the Project Expenditure table fully?	✓
Do not include claim forms or other communications with this report.	