Department for Environment Food & Rural Affairs

DARWIN INITIATIVE

Foreign & Commonwealth Office

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# Darwin Plus: Overseas Territories Environment and Climate Fund Annual Report

**Important note** *To be completed with reference to the Reporting Guidance Notes for Project Leaders:*

*it is expected that this report will be about 10 pages in length, excluding annexes*

**Submission Deadline: 30th April 2018**

## Darwin Plus Project Information

| | |
|---|---|
| Project reference | DPLUS064 |
| Project title | Characterising Bermuda's baitfish populations to improve management and fishery sustainability |
| Territory(ies) | Bermuda |
| Contract holder institution | Bermuda Zoological Society |
| Partner institutions | Bermuda Government DENR, Bermuda Institute of Ocean Sciences, Murdoch Marine |
| Grant value | GBP189,729 |
| Start/end date of project | April 2017 – September 2019 |
| Reporting period (e.g., Apr 2017-Mar 2018) and number (e.g., AR 1,2) | April 2018-March 2019<br>AR2 |
| Project leader name | Joanna Pitt |
| Project website/blog/Twitter | |
| Report author(s) and date | J.M. Pitt, S.R. Smith, T.J. Murdoch, G. Goodbody-Gringley and J.L. Welch |

## 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 their life history characteristics are poorly understood. Reported catches of all baitfish groups have declined over the past 25 years, but it is unclear whether this indicates declining populations or changes in fishing practices. Current management restricts the size and type of nets that may be used, and prohibits net fishing in four inshore bays. However, a greater understanding of the abundance, distribution, life history and population genetics of these species will create opportunities for a wider range of management measures to be applied to these fishes, and will inform discussions with stakeholders regarding the need for additional management and the forms that it might take.

This project is describing the annual cycles in abundance and distribution of baitfishes around Bermuda, together with their life history (i.e. age, growth and reproduction) and population genetics. We are working to engage commercial and recreational fishers in order to examine bait fishing and bait use practices, including attitudes towards alternative baits, and to raise awareness of the status of baitfish populations. This will contribute to a revised management plan for baitfish species in Bermuda, improving the sustainability of the fishery while ensuring 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, 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 provides the 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 in the final stages of the project, when the reports are complete and the revised management plan is being developed. The MRB's support for the project has been helpful in engaging the new permanent secretary and the two ministers that have had responsibility for DENR since the 2017 election.

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. The fisher surveys and interviews conducted this year are an important part of engaging these stakeholder groups.

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 Progress

### 3.1 Progress in carrying out project Activities

#### 3.1.1 Determining the annual cycle of baitfish abundance

Baitfish presence and school composition were monitored at 6 bays at least weekly using visual surveys that concluded in August of 2018 (activity 1.1 / 1.345). More than 900 visual assessments were completed across these and 40 other opportunistically surveyed sites (see 2017-18 annual report).

Based on these observations, a bait fish abundance index has been developed as the most appropriate way of presenting and analysing the data. The 2-dimensional area of the school (in $m^2$) is multiplied by a visually assessed density category, such that Sparse = 1, Medium = 2, and Dense = 3. Where multiple species occur in a given school, the density index is divided by the number of species seen. We are still working on the best way to graphically represent this large amount of data.

Evaluation of the monitoring observations revealed some variability in the annual cycles of the 6 key inshore baitfish species. The endemic Bermuda anchovy, *Anchoa choerostoma*, is common from March through November. Observations suggest that recruitment of this species occurs at the western end of the island, with greater numbers observed there from March through July, and then more frequent observations in central and eastern areas from August through November suggest an eastwards migration over the course of the summer. As all of our regular monitoring bays were in the east end, the wide-ranging sampling undertaken for the life history work and the other opportunistic visual surveys were critical to detecting this. The largest, densest schools of this species were observed in August and September. Reef silversides, *Hypoatherina harringtonensis*, were most commonly observed inshore from late August through November. Dwarf herring, *Jenkinsia lamprotaenia*, are most commonly observed from April through August, with peak abundance in July. A large pulse of juvenile Redear herring, *Harengula humeralis*, typically appears in June and July, such that overall abundance of this species peaks in the late summer / early fall when both juveniles and adults are common. Threadfin herring, *Opistenema oglinum*, and Spanish sardine, *Sardinella aurita*, were the least abundant species in all surveys (see also section 3.1.4). The relative scarcity of these species is corroborated by both fisheries landings reports and surveys of commercial and

recreational fishers (see 3.1.5). Small numbers of adults have been observed inshore in deeper sheltered areas during the winter months, corresponding to the peak months for fisheries landings in the past, and juveniles appear in shallow bays from June through August.

The period of peak baitfish abundance in inshore waters was identified as July through October (Figure 1), with dense schools ("bait balls") forming August through October (activity 1.6). Turtle Bay, the most exposed site, had the least amount of baitfish over time, likely due to the rougher conditions. Somewhat disappointingly, the two monitoring bays that are closed to fishing do not appear to have significant baitfish presence for much of the year (Figure 1).

Figure 1. Presence / absence of the various baitfish species at the key monitoring sites. Bays are listed as open to fishing (blue) or closed to fishing (red). Green squares indicate the presence of a given species at that site during at least one visit that month. Grey cells indicate gaps in sampling. (S. aur = *Sardinella aurita*, J. lam = *Jenkinsia lamprotaenia*, A. cho = *Anchoa choerostoma*, H. hum = *Harengula humeralis* and H. har = *Hypoatherina harringtonensis*) The number of baitfish species observed in a given month is listed in the bottom row.

| Baileys Bay | Month | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 80 samples | S. aur | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| open | J. lam | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | A. cho | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | H. hum | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| | H. har | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| | species | 2 | 2 | 4 | 3 | 3 | 1 | 3 | 1 | 3 | 3 | 3 | 2 | 3 | 4 | 3 |

| Turtle Bay | Month | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| >60 samples | S. aur | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| open | J. lam | | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | A. cho | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | H. hum | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | H. har | | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | |
| | species | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |

| Stokes Bay | Month | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| >60 samples | S. aur | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| open | J. lam | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | A. cho | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| | H. hum | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | H. har | | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | |
| | species | 0 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 0 |

| Coney Causeway | Month | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 59 samples | S. aur | 0 | 1 | 0 | 0 | 0 | | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| open | J. lam | 0 | 1 | 0 | 1 | 0 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | A. cho | 1 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| | H. hum | 1 | 1 | 0 | 1 | 1 | | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |
| | H. har | 0 | 0 | 1 | 1 | 1 | | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| | species | 2 | 4 | 2 | 4 | 3 | | 3 | 4 | 3 | 3 | 3 | 2 | 3 | 3 | 3 |

| Coney Cove | Month | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 59 samples | S. aur | | 1 | | 0 | 0 | | 0 | 1 | 0 | 0 | 0 | | 0 | 1 | 0 |
| open | J. lam | | 1 | | 1 | 0 | | 1 | 1 | 1 | 0 | 1 | | 1 | 1 | 1 |
| | A. cho | | 1 | | 1 | 0 | | 0 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 |
| | H. hum | | 1 | | 1 | 0 | | 0 | 0 | 0 | 0 | 0 | | 1 | 1 | 1 |
| | H. har | | 1 | | 1 | 1 | | 1 | 1 | 1 | 1 | 0 | | 0 | 0 | 0 |
| | species | | 5 | | 4 | 1 | | 2 | 4 | 3 | 2 | 2 | | 3 | 4 | 3 |

| Shelly Bay | Month | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| >60 samples | S. aur | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| closed | J. lam | | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | A. cho | | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | H. hum | | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | |
| | H. har | | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | |
| | species | 0 | 4 | 2 | 3 | 2 | 3 | 1 | 0 | 1 | 1 | 2 | 2 | 2 | 2 | 0 |

| Whalebone | Month | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| >60 samples | S. aur | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| closed | J. lam | | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | A. cho | | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | H. hum | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | H. har | | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | species | 0 | 2 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

These data drove the timing of the broadscale survey, which was conducted primarily in September and October to capture the peak abundance of the greatest number of species. However, while the Bermuda anchovy, Reef silverside and Redear herring were most abundant and schooled more densely during these months, the Dwarf herring were most abundant in late spring and early summer. Further, although juvenile Spanish sardine and threadfin herring are more likely to be found during the summer, adults of these species are more commonly present inshore during the winter months. This has implications for interpreting the results of the

broadscale survey, and it should be acknowledged that Dwarf herring, Spanish sardine and Threadfin herring will likely be under-represented in those data.

Temperature loggers were placed at 4 locations in the spring of 2018 (activity 1.2) but appear to have been lost during winter storms. We have access to temperature climatology based on previous years for two of our sites and are currently seeking alternate sources of temperature data that will be relevant to our other monitoring sites.

While the data are in hand, the report on this work (activity 1.7) is still being finalised, but revisions should be complete by the end of May.

Cameras have been in place at 6 sites (3 that are closed to net fishing and 3 that are unrestricted) for between 7 and 20 months to monitor fishing / poaching activity (bonus activity replacing activity 1.1). Although the coverage has some gaps related to inconsistent camera functioning, these cameras have detected 80 fishing events at one unrestricted site over 17 months (Coney Cove, a small enclosed bay), 7 fishing events at another unrestricted site over 12 months (Bailey's Bay, a larger bay with a variety of habitats), and one incident of poaching in one of the closed bays over 15 months (Shelly Bay). The majority of fishing events utilised a cast net (83% of events at Coney Cove, 43% of events at Bailey's Bay and the poaching incident at Shelly Bay). However, there were at least 4 significant commercial-scale harvests at Bailey's Bay that were caught on camera, even though the time lapse only recorded images at 30 minute intervals. Data on fishing intensity in key locations will help demonstrate the need for more comprehensive management.

### 3.1.2 Age, growth and reproduction studies

This is the largest and most complex component of this project. Weekly sampling for life history parameters is complete (activity 2.1), and 6,800 samples have been processed (activities 2.2-2.4). This has helped to develop an understanding of the reproductive periodicity of the various baitfish species in Bermuda.

Reproductively active Bermuda anchovy, *A. choerostoma* (2,368 samples), were found from March through November, although developing oocytes have been found as early as mid-February. Actively spawning individuals were usually found around the full moon, and occasionally around the new moon. Reproductively active Reef silversides, *H. harringtonensis* (1,999 samples), were found from April through mid-August. They are partial spawners and reproduce every two weeks around the new and full moon. Although reproductively active Dwarf herring, *J. lamprotaenia* (1,715 samples), have been found year round, this species may produce fewer oocytes in the winter compared to summer. This is most noticeable in December, when some reproductively inactive individuals were found. Dwarf herring are partial spawners, and appear to spawn every six weeks around the full or new moon with some exceptions. Dwarf herring are most reproductively active from April through July. The Redear herring, *H. humeralis* (580 samples), spawns from April through August. The largest pulse of juveniles appeared in June and July. Otolith ageing of the juvenile samples collected will help to clarify the spawning cycle of this species. Threadfin herring, *O. oglinum* (61 samples), and Spanish sardine, *S. aurita* (77 samples), were the least abundant species in all surveys (see 3.1.1 and 3.1.4) and thus also in the samples. The largest numbers of juveniles were found in June and July. Data collected from sampling suggests that these species do not spawn in the winter months, although they appear to be most abundant near shore around that time. Otolith ageing of the juveniles collected will help describe the spawning cycle of these species.

A number of extracted gonads are still being processed for batch fecundity (activity 2.5). Otolith processing (activity 2.6) is still underway. The development of processing protocols to expose daily growth rings has not been as straightforward as expected, and progress on this activity has been slower than anticipated. The project technician has agreed to continue working part time on a voluntary basis to ensure that this work is completed. A total of 585 gonads were sent for histological processing at the start of February (activity 2.7). Processing was delayed as we were not able to ship the samples via courier as planned (see section 5). Slides are now being shipped back for reading. The report on this work (activity 2.8) is due by the end of September of 2019, and should still be on time despite these delays.

### 3.1.3 Population genetics

The genetics work (activities 3.1-3.3) was completed in year 1, and we obtained sequences from all six of Bermuda's baitfish species. GGG performed some additional regional

comparisons in year 2. The levels of genetic diversity within and among baitfish assemblages in Bermuda were high, indicating that Bermuda's various baitfish species consist of single populations with high rates of mixing and local connectivity. However, with the exception of *H. humeralis* and the endemic *A. choerostoma*, significant genetic differentiation and population structure were found when comparing Bermuda's baitfish populations with conspecifics from other regions, suggesting limited gene flow between regions for these species.

This work was presented as a poster at the 71st Gulf and Caribbean Fisheries Institute meeting in November (see Annex 3A, attached separately) and a scientific paper is in the final stages of revision with the online journal PeerJ.(see Annex 3B for the abstract) (activity 3.4).

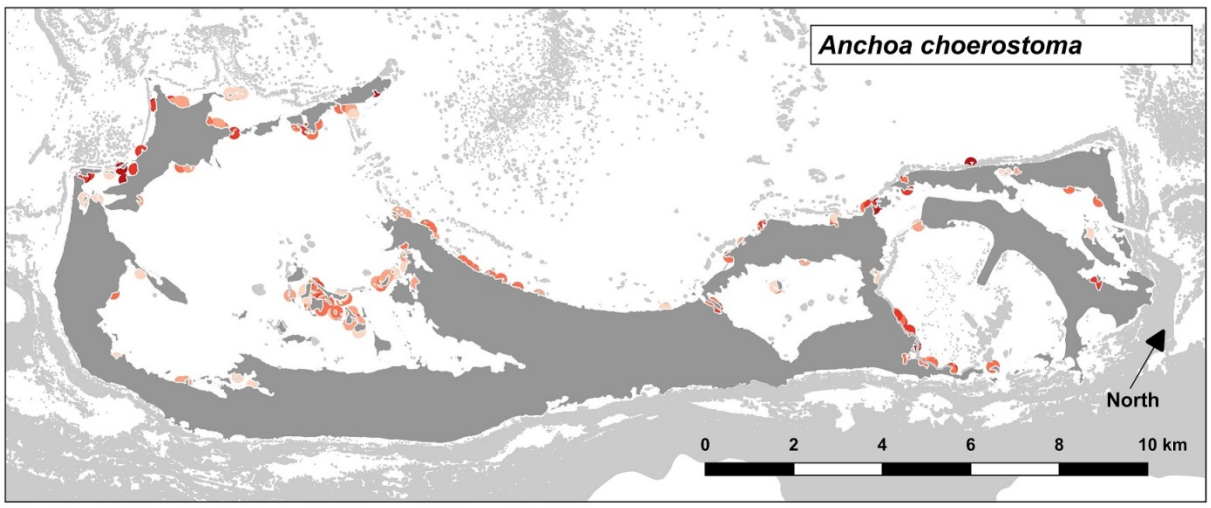
Genetic sequences are currently being uploaded to Genbank (activity 3.5) as part of the publication process.

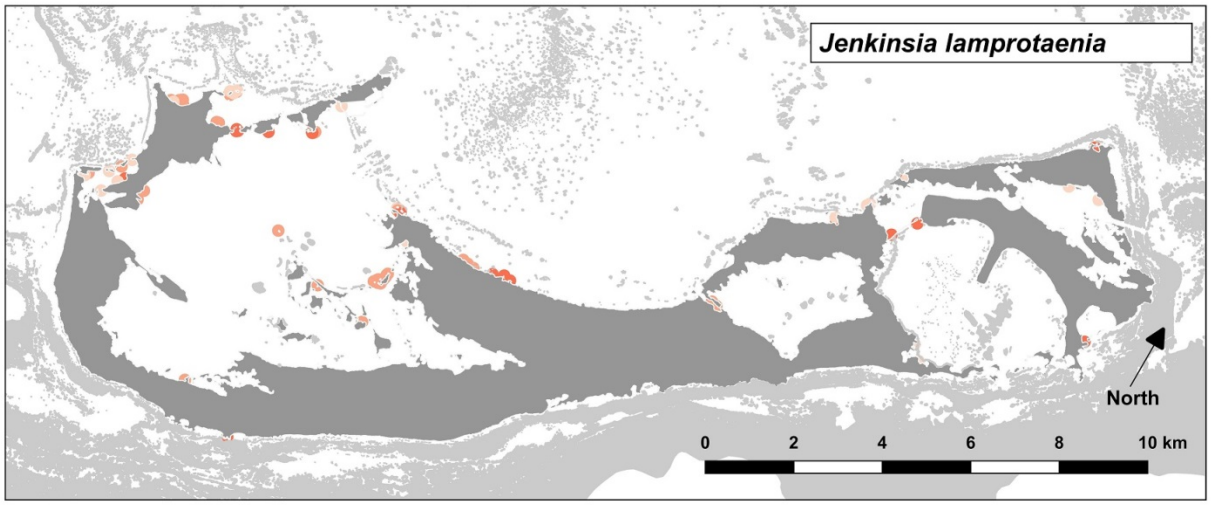
### 3.1.4 Broadscale survey of peak baitfish abundance / distribution

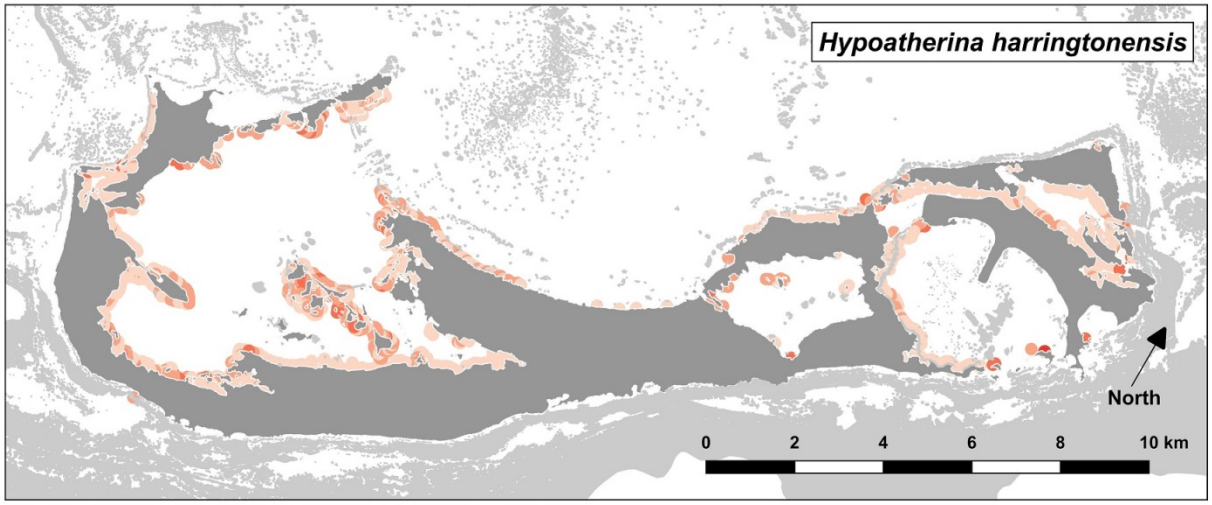
Testing in April of 2018 (activity 4.1) demonstrated that the aerial drone was able to distinguish denser schools in clear water over sandy bottoms, but had trouble detecting sparsely schooled fish over more mottled benthos. Between mid-July and November 1 of 2018, we surveyed 95 km of shoreline, including over 150 inshore bays, for baitfish (activity 4.2). Most surveys were conducted in September and October, covering large areas of adjacent shoreline in a single day to get a realistic overview of baitfish presence / absence, school sizes and species composition, while avoiding confounding by meso-scale movements between surveys. We used the aerial drone where possible, supplemented by visual surveys in areas where the drone was not permitted to fly (i.e. around the airport or too close to houses) or in conditions under which detection of baitfish was less reliable. With practice, visual identification of baitfish species from a stationary or slowly moving boat became a practical way of expanding our spatial coverage, such that the area we covered was 3 times our initial target for the same number of field days and included a significant proportion of Bermuda's inshore waters. Species composition was validated with net sampling and snorkel surveys as required (activity 4.4). Schools observed in situ were recorded approximately to scale directly onto printed maps, with additional notes on estimated school size, then digitised into mapping software by eye according to details visible in the software's satellite-based imagery (activity 4.3). Schools observed in drone images were digitised directly into mapping software (activity 4.3)

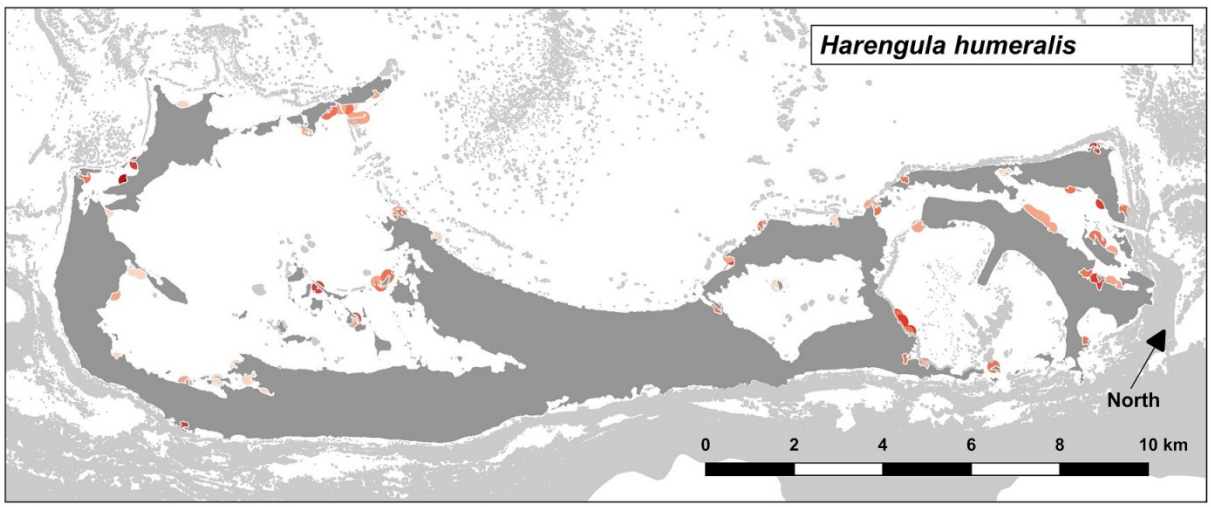
Draft distribution maps for each species are presented below (Figure 2), with each dot representing a school, and colour intensity reflecting an abundance ranking that factors in school size and density (see section 3.1.1), then brackets similar values into ranks. It was not possible to show school size directly on the maps because of scale issues. We are still refining the rank system and colour intensity scale to best illustrate spatial variations in abundance. While it has been a bonus to acquire so much data, this has created presentation challenges.

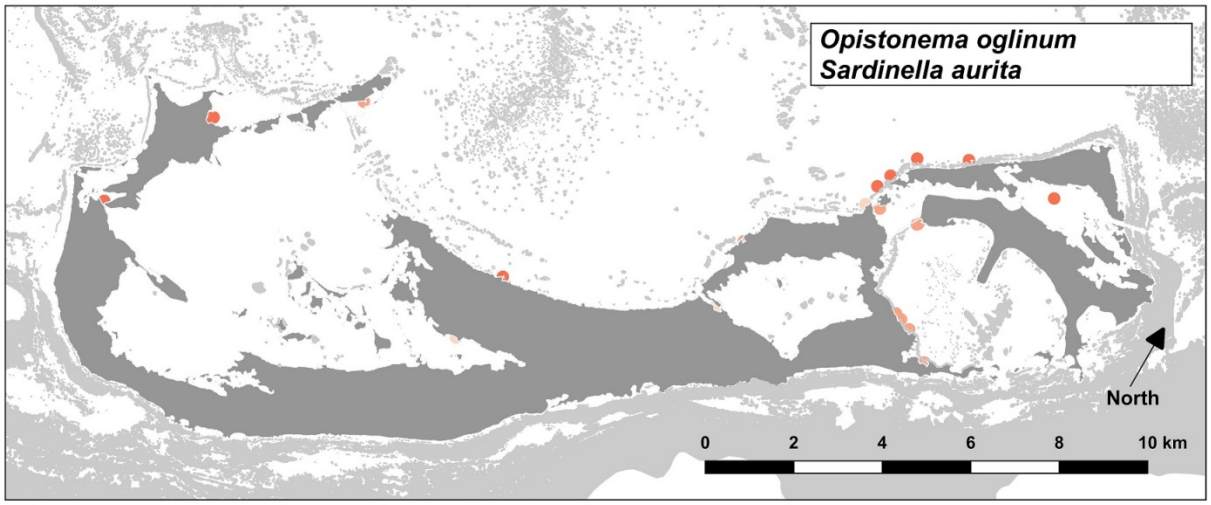
Figure 2. Distribution of baitfish species around inshore waters of Bermuda during peak abundance (September 13 to November 1, 2018). Each dot represents a school, and colour intensity reflects abundance ranking.




Jenkinsia lamprotaenia
North
0 2 4 6 8 10 km


Hypoatherina harringtonensis
North
0 2 4 6 8 10 km


Harengula humeralis
North
0 2 4 6 8 10 km




The Bermuda anchovy, *A. choerostoma*, was present in sheltered bays and inlets around the island, forming very dense schools in some locations, usually close to the bottom. As acknowledged in section 3.1.1, Dwarf herring, *J. lamprotaenia*, do appear to be under-represented in the broad-scale survey data as their abundance peaks earlier in the year. Efforts to develop an alternative yet still valid way of presenting the relative abundance of this species are ongoing. Reef silversides, *H. harringtonensis*, were present in loose shoals of low density along most lee shores, occupying the surface layer over deeper water than utilised by the other species. The Redear herring, *H. humeralis*, was the most abundant of the larger species and was often found in the slightly deeper areas of sheltered bays, schooling below denser schools of Bermuda anchovy. The Spanish sardine and Threadfin herring were uncommon, so are presented on the same graph. Some mixed schools in the east end contained larger juveniles of these species and a few other smaller schools were observed. Although the data and draft maps are in hand, we are still refining the graphics and finalising the report on this (activity 4.5). Revisions should be complete by the end of May.

### 3.1.5 Survey of baitfishing, bait use and fisher perceptions

The mail survey (activity 5.1) was sent to registered fishers with the winter edition of the Fisheries Newsletter, accompanied by a short article in the newsletter itself (see separately attached Annex 4). To date, 11 responses have been received and tabulated, equating to 6% of active, non-specialist commercial fishers. Additional copies were handed out at a recent meeting and sent out via email to try to boost the response rate. Responses so far indicate that commercial fishers are more likely than recreational fishers to utilise different types of bait to target different species, and that most of them catch some bait themselves but also purchase bait from other fishers or other sources. Many full time fishers take advantage of their option to import frozen bait duty-free. About 63% of commercial fishers already utilise their processing scraps for chum, and of the remainder, about half were interested in this approach whether for their own fishing or to sell.

Semi-structured interviews with the two specialist commercial bait fishers have been conducted (activity 5.2) and provided some interesting insights. The increased prevalence of derelict boats and large debris items in many inshore areas since the spate of hurricanes that hit Bermuda between 2014 and 2016 was raised as an issue, not only because it contaminates these important habitats, but also because it reduces the area that is available for hauling seine nets, concentrating this commercial-scale bait fishing activity into fewer bays. These fishers also noted that adults of the larger bait species, particularly the Spanish sardine, are now found more frequently in deeper areas than in the shallow bays. This phenomenon of pushing population remnants deeper, beyond the range of easy capture, has been noted in other heavily exploited fisheries but may also be a result of changing temperature regimes. One fisher noted that the peak abundance of Dwarf herring seems to have shifted later in the year. Previously, this species was more abundant in April and May, and thus was targeted then to provision the bait purchase market in the early part of the summer, while the Bermuda anchovy was more abundant in the later part of the summer and targeted for marketing in late summer and autumn. The logistics and high cost of keeping fish caught in the autumn frozen over winter to provision the spring and early summer market are prohibitive, and this has affected sales to

recreational purchasers during this period. Catches of smaller Redear herring in the spring have increased to compensate for the lower abundance of Spanish sardine and the delayed appearance of dwarf herring. Netting of the abundant but infrequently eaten blue runner, *Caranx chrysos*, as an alternative source for chum was discussed.

The roving shoreline survey of recreational fishers (activity 5.3) was augmented by an online survey targeting those recreational fishers who fish primarily from boats. Sharing this survey via the local angling clubs and the Marine Resources Facebook page also raised awareness of the project in general. A total of 41 surveys were completed (see separately attached Annex 5) – 30 in person and 11 online, but all data was entered into the SurveyMonkey online platform to facilitate analysis. Most recreational fishers (75%) catch at least some of the bait that they use. Although most expressed a preference for mid-sized fish, they tend to fish for bait opportunistically at times of year when they are actively fishing and take whichever species are available. Almost all respondents (92%) expressed an interest in purchasing alternative bait to use as chum. However, awareness of the bays that are closed to net fishing was poor amongst recreational fishers, with 45% of respondents stating that they did not know about these areas.

The consensus across all respondents is that, while the abundance of the smaller baitfish species seems to have remained relatively consistent overall despite year to year variability, there has been a notable decline in the Spanish sardine, *S. aurita*, and the more knowledgeable commercial fishers noted the same for the Threadfin herring.

Analysis of these datasets is still underway and the report (activity 5.4) is expected to be done by the end of May (about two months behind schedule).

### 3.1.6 Publicity

An article on the project was published in the summer edition of the DENR / BAMZ newsletter, *Envirotalk*., and shared further via the Marine Resources Facebook page (see Annex 6 link). DEFRA and Darwin Plus were appropriately credited.

## 3.2 Progress towards project Outputs

Data on the **annual cycle in baitfish abundance and distribution** are in hand, providing evidence of differences in availability and peak abundance amongst species (see section 3.1.1). The report **(Output 1)** is currently being revised, with completion expected by the end of May 2019. A key goal of this work was to acquire data to inform the timing of the **broadscale survey of baitfish distribution and abundance**, which was completed at a scale that exceeded the original target area. Preliminary maps of these data are presented and discussed in section 3.1.4, and the report on this component **(Output 4)** will be finalised by the end of May 2019.

The **age, growth and reproduction study** is the largest component of this project. Over 6,800 specimens have been processed (see section 3.1.2) and, in terms of change from baseline, we now know a lot more about baitfish than we did two years ago! Macroscopic observations of gonads have demonstrated the seasonality of reproduction for the various species, and it appears that the three focal species of small baitfish reproduce at different times of year. Histology to confirm this is pending. Although some components, such as otolith ageing, are progressing more slowly than expected, the report on this work **(Output 2)** is not scheduled to be completed until the end of September of 2019.

The **genetic study** is complete and has provided information that is useful for baitfish management **(Output 3)**. Results showing high rates of local connectivity among sites for all species imply a reduced need for an evenly distributed network of closed areas, and would allow any additional closures to be selected in a more flexible manner that may serve to reduce conflict. However, with the exception of *H. humeralis* and the endemic *A. choerostoma*, significant genetic differentiation and population structure were found when comparing Bermuda's baitfish populations with conspecifics from other regions, suggesting limited gene flow between other regions and Bermuda for these species. Limited regional connectivity has implications for management, as strong genetic divergence suggests that populations in Bermuda are predominantly self-seeding and thus not likely to be replenished from distant populations. These results therefore support precautionary management of baitfish species in Bermuda.

This work was presented as a poster at the 71st Gulf and Caribbean Fisheries Institute meeting in November (see Annex 3A, attached separately) and a scientific paper is in the final stages of revision with the online journal PeerJ (see Annex 3B for the abstract) (Output 3.2). Genetic sequences are currently being uploaded to Genbank (Output 3.3) as part of the publication process.

**Surveys of the three bait fishery sectors** have been conducted, although we are hoping to boost the number of respondents from the commercial sector. The interviews with the commercial fishers who specialise in bait fishing were particularly informative, as we have a much greater understanding of the mechanics of the bait market. The report on this activity **(Output 5)** has been delayed until end of May 2019.

**Cataloguing of imagery (Output 6)** will take place later in 2019. The image library will not be as extensive as originally anticipated because of changes in methodology.

As this project primarily comprises a number of research strands that aim to fill recognised data gaps, most of the output indicators are based on the reports on this work being received by the DENR Marine Management team. The revised management plan that will be the primary outcome of this project will utilise information from the reports, which will be available far sooner than peer-reviewed journal articles.

Other outputs relating to increased local capacity via the purchase of scientific equipment for the DENR Marine Management Section were detailed in the 2017-18 annual report.

## 3.3 Progress towards the project Outcome

The main outcome of this project will be the development of a revised plan for managing baitfish in Bermuda, with the expectation that improved management will contribute to the stability of these populations, allowing them to continue to fulfil their important ecological and economic roles. As such, DENR's receipt of the output reports and the completion of the management plan are the obvious outcome indicators. The success of the revised management plan going forward will require buy-in from non-government stakeholders, particularly commercial fishers, and work to support this should also be considered as contributing to the outcome.

Increased knowledge about the life history of these focal baitfish species and an understanding of their annual cycles will inform and support new management approaches as we develop a revised management plan. However, differences in seasonality between species mean that a "one size fits all" approach may not work. The period of peak baitfish abundance in inshore waters has been identified as July through October, with the greatest numbers, particularly of juveniles, present in the late summer / early autumn. This highlights the vulnerability of these species to the hurricanes and tropical storms that often impact Bermuda during this season, and may be used to justify adaptive management measures such as temporary moratoria on bait fishing in the wake of damaging storms.

The genetic study (Output 3) has provided scientific data to support precautionary management of baitfish in Bermuda, but indicates that the spatial distribution of any ecosystem-based protective measures can be flexible (see discussion in Section 3.2). This information is both useful for the development of the management plan and helpful for outreach efforts that aim to promote buy-in from stakeholders. The bonus camera data showing fishing intensity in key locations will also help demonstrate the need for more comprehensive management.

Engaging with the public and fishers to build support for improved management has taken place via articles in outreach publications that have been shared via social media, opportunistically during field work, and through the surveys and interviews contributing to Output 5. The understanding we have gained regarding the bait market, from both sales and purchasing perspectives, has been extremely valuable, and will be key to developing an a fair and workable management plan. A key insight from the recreational surveys has been the lack of awareness regarding the bays that are closed to net fishing (see 3.1.5). As a result, we have already started discussions about sourcing funds to place signage at these bays, and at any other locations where spatial management may be deemed appropriate. Greater awareness and prominent signage should both promote compliance with the revised management plan that is the official project outcome, contributing to its effectiveness and thus the wider conservation and management goals.

As outlined in the proposal, the reports should all be complete and submitted by September 2019. Development of the revised management plan will be undertaken by DENR staff, including project leader JP, but no further grant funds are required for this process. The target deadline for the completion of the draft management plan is December 2019, allowing 3 months for the process once the reports are complete. Stakeholder consultation will begin during the first quarter of 2020. Thus, it is expected that the broader outcome will still fall within the 2019-2020 financial year.

## 3.4 Monitoring of assumptions

A key assumption was that of fisher co-operation with the surveys and interviews. In order to promote co-operation, articles were published in the summer issue of DENR's public outreach bulletin *Envirotalk* and the winter Fisheries Newsletter, and the survey was publicised via our Facebook page. The risk was also mitigated by engaging with fishers on an opportunistic basis and having informal conversations about the project to build support. Response amongst recreational fishers was good, in part because we developed an online survey to reach a broader audience. We emailed the commercial fisher surveys a second time to some recipients and handed out additional copies at a recent meeting of the Fishermen's Association of Bermuda in order to boost participation. Our Fisheries Extension Officer has also conducted a few surveys in person.

We also assumed that the protocols for the preparation and reading of otolith daily rings would be relatively simple to develop. This is an area where perhaps we were a bit too optimistic! However, there is time to complete this work before the report deadline, with technician JW offering to work part-time on a voluntary basis to do so.

Acceptance of, and compliance with, the revised management plan developed as a result of this work is an over-riding assumption, as is the expectation that the revised management measures will be sufficient to contribute to the future stability of baitfish populations in Bermuda. Indeed, the effects of stochastic environmental factors on baitfish populations may be greater than expected. As detailed in section 3.3, we are working to mitigate these risks by gathering as much data as possible to understand biological cycles, external threats and market pressures. We are also engaging with fishers across the various sectors to promote awareness and support for management measures. It is hoped that these approaches will enable us to explore and build support for a diversity of management strategies in a flexible manner.

## 3.5 Project support to environmental and/or climate outcomes in the UKOTs

The development of a revised plan for managing baitfish in Bermuda, with the expectation that improved management will contribute to the future stability of these populations, will help ensure that these species continue to fulfil their important ecological role while also contributing to the local economy and local food security. 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.

Any project that engages with resource users also raises awareness of environmental issues, and positive engagement can help promote more environmentally responsible behaviours and stewardship. Outreach and community engagement associated with this project has helped raise the profile of DENR and provided opportunities to open discussions about fisheries and other associated environmental issues such as climate change.

The project has also added to local fisheries management capacity by providing an opportunity for a young Bermudian who has recently completed his undergraduate degree to work alongside DENR staff, developing his skills in fisheries biology techniques and exposing him to the practical aspects of marine environmental management that cannot really be taught in a university setting. Another young Bermudian has participated in the project as an intern this year, assisting with the fisher surveys and otolith preparation.

## 4. Monitoring and evaluation

At the start of the project, as we were testing the methods and then revising them, regular, planned meetings were critical. 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 sharing of data, which in turn made monitoring 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 of progress, reducing the burden of monitoring. See sections 3.2 and 3.3 for discussion relating the project outputs and the relevant indicators to the expected outcome.

## 5. Lessons learnt

A key lesson learnt this year is 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 can 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.

## 6. Actions taken in response to previous reviews (if applicable)

## 7. Other comments on progress not covered elsewhere

From an administrative perspective, dealing with fluctuations in the GBP to USD exchange rate has been challenging. When writing cross-currency proposals, it is important to build in a small margin to account for this, and to be prepared to be flexible. However, as discussed in the half year report, we experienced difficulties with the final 'in arrears' claim of 2017-18 (made based on total actual expenditure) that was subject to a long delay between the currency equivalency calculations and the actual payout, during which time exchange rates fluctuated wildly. As a result we were short $on funds to cover monies already paid out. After discussions with LTSI, this shortfall has been included in this year's claim, under 'Other' expenses, and is being paid for by savings achieved under the aerial drone survey consulting work that resulted from using DENR vessels for 4 survey days in areas where drone work was not possible. Further, our grant account does not have a large surplus, so our partners and contractors were forced to wait for payment. This hinders our ability to engage certain providers in the future. Further, a significant amount of the project leader's time has been spent chasing funds and dealing with the fallout. Partnering with a large UK-based organisation for fiduciary purposes, so that all grant funds could be disbursed into local currency in advance, could help with this. However, this would increase overhead costs and could reduce the ability of OTs to determine their own conservation agendas if collaborators with similar interests are not available.

## 8. Sustainability and legacy

This was project was initiated locally and supported by DENR to address key gaps in the data required for more comprehensive management of baitfish species in Bermuda. Project leader JP will work with the rest of the DENR Marine Management team to develop an improved management plan using the information presented in the output reports from this project. Despite a change in Government, we have continued support at the ministerial and cabinet level, as well as the support of the Marine Resources Board, so the political will is in place for such a plan to be implemented. Outreach articles, our fisher surveys and field sampling have all provided opportunities to engage with the various fisheries sectors to discuss the importance of baitfish management. Importantly, incorporating fishing practices and fishers' opinions into the

discussion from the start should facilitate the development of a management plan that will be accepted by the commercial and recreational fishing communities. A more sustainable baitfish fishery will have lasting economic and ecological benefits.

## 9. 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. During the past year, there have been two short outreach articles (see Annexes 4 and 5) where this support was mentioned in the text. Darwin Plus / Defra are acknowledged in the funding section of the genetics paper that is in revision with PeerJ and the Darwin logo was included on the poster when this work was presented at the GCFI meeting (see Annex 3A).

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 BZS staff and associates, BIOS scientists, members of the Marine Resources Board, and anyone who was associated with the lionfish work undertaken previously.

## 10. Project Expenditure

**Table 1: Project expenditure <u>during the reporting period</u> (1 April 2017 – 31 March 2018)**

| **Project spend (indicative) in this financial year** | **2017/18 D+ Grant (£)** | **2017/18 Total actual D+ Costs (£)** | **Variance %** | **Comments (please explain significant variances)** |
|---|---|---|---|---|
| Staff costs | | | | |
| Consultancy costs | | | | |
| Overhead Costs | | | | |
| Travel and subsistence | | | | |
| Operating Costs | | | | |
| Capital items | | | | |
| Others (Please specify) | | | | |
| **TOTAL** | | | | |

## Annex 1: Report of progress and achievements against Logical Framework for Financial Year 2018-2019 – <u>if appropriate</u>

| Project summary | Measurable Indicators | Progress and Achievements April 2018 - March 2019 | Actions required/planned for next period |
|---|---|---|---|
| ***Impact***<br>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. | | | [redacted] |
| ***Outcome***<br>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.<br>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. | We now have an understanding of the annual cycles of baitfish abundance and their broadscale distribution, and are improving our understanding of the life history of these species. We have demonstrated local genetic connectivity but regional isolation for Bermuda's baitfish species. We have gained valuable insights into bait fishing across the various fishery sectors, as well as the market for bait, and engaged with fishers from all sectors. | All outstanding reports / Outputs will be completed during the first half of 2019-20, and a draft of the revised management plan will be developed by year end. The work this year should enable us to develop a robust management plan that will be supported by key stakeholders. |
| **Output 1.**<br>Report describing the annual cycle of baitfish populations | 1.1 Report completed and provided to DENR | We now have an understanding of the annual cycles of baitfish abundance and the variability between species (see section 3.1.1). We are working to develop suitable graphical presentations for the large amount of data involved and the report is still being finalised. | |
| 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 appear to have been lost during storm activity. We have access to temperature climatology data for several of our sites and are currently seeking alternative sources of relevant temperature data. | |

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| 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 have been 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 is currently being revised and appropriate graphics developed. |
| **Output 2.**<br>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<br>2.2 Scientific publication | This work is still underway. See section 3.1.2 for details of progress. |
| 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. We were often able to get samples from more than one day per week, which provides increased resolution when trying to determine spawning times. |
| 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 have been measured, weighed and dissected, with otoliths extracted and more than 600 gonads preserved for histology and batch fecundity. |
| Activity 2.5 - Evaluate batch fecundity for up to 20 ripe ovaries per month, as available. | | Work on batch fecundity samples is underway. |
| 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 has not progressed as efficiently as anticipated, with delays meaning that this work will continue into the next few months. |
| Activity 2.7 - Have monthly ovary samples processed for histological analysis and read slides to evaluate spawning condition. | | 585 ovary samples have been processed for histology and slides are being shipped back for analysis. |
| Activity 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 | | This activity will take place during April – September 2019. |

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| silverside. Include potential management measures based on these characteristics. | | |
| **Output 3.**<br>Population genetics analysis of 3 small-bodied baitfish species published and sequences uploaded to publicly available databases. | 3.1 Advisory report completed<br>3.2 Scientific publication<br>3.3 Sequences uploaded | The genetic study indicated genetic mixing across all of Bermuda for the various species. Levels of intraspecific diversity are suggestive of limited external input for the non-endemic species. DENR has been provided with a summary of results, and the scientific publication is in the final stages of revision. Sequences of Bermuda's baitfish species will be available via Genbank by June. |
| 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 6 local inshore baitfish species in this analysis and GGG performed some additional comparative work during 2-18-19. DENR has received a summary of the findings. A scientific publication is in the final stages of revision with the online journal PeerJ, with publication expected during by June 2019. |
| 3.5 - Upload sequences to publically available databases: the NCBI database, GenBank, and the barcoding of life data systems database, BOLD. | | Sequences are being uploaded to Genbank during April 2019. |
| **Output 4.**<br>Report describing broadscale survey of peak baitfish abundance / distribution | 4.1 Report provided to DENR | We have data on the distribution, relative abundance and habitat utilisation of the various baitfish species (see section 3.1.4). We are refining the maps and the report is in draft form. |
| 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.<br>Activity 4.3 Select and analyse 300 aerial images for presence and spatial extent of baitfish schools.<br>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 in large swaths to get a realistic overview of baitfish presence / absence, relative abundance and species composition, while avoiding confounding by meso-scale movements between surveys. Data have been entered into mapping software. |
| Activity 4.5 Prepare report on the abundance and distribution of baitfish around Bermuda. | | Map graphics have been developed and are currently being refined. The report is in early draft form. |
| **Output 5.**<br>Report on baitfishing, bait use and fisher perceptions, with management suggestions | 5.1 Report provided to DENR | Surveys and interviews have been conducted, although we are trying to boost the response rate from the commercial fishery. The report should be complete by the end of May. |

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| 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 (Annex 4) and 11 responses have been received so far (6% of non-specialist commercial fishers), although more copies of the survey were handed out at a recent meeting with fishers. Efforts are underway to boost the response rate. This has led to some delays in the finalisation of the report. |
| 5.2 Develop questions and conduct semi-structured interviews with specialised bait fishers. | | In-depth interviews were conducted with the 2 specialist bait fishers. |
| 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. | | Analysis of the results is currently underway. |
| **Output 6.**<br>All imagery curated and stored at BAMZ Natural History Museum for other researchers to access upon request | 6.1 Images provided to BAMZ | Activities contributing to Output 6 will take place later in 2019. |

## Annex 2: Project's full current logframe as presented in the application form (unless changes have been agreed) - if appropriate

*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:**<br>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:**<br>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.<br>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<br>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:**<br>**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.<br>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<br>2.2 Scientific publication | 2.1 Report provided to DENR<br>2.2 Publication in press or available online | Adequate numbers of each species available for sampling throughout the year.<br>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<br>3.2 Scientific publication<br>3.3 Sequences uploaded | 3.1 Report provided to DENR<br>3.2 Publication in press or available online<br>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 two 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 publically 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 3 Onwards – 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. | 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. | |