Darwin Plus:
Overseas Territories Environment and Climate Fund

Final Report

***Important note** To be completed with reference to the Reporting Guidance Notes for Project Leaders: it is expected that this report will be a maximum of 20 pages in length, excluding annexes*

Darwin Project Information

Project Ref Number	DPLUS001
Project Title	Bermuda Invasive Lionfish Control Initiative
Territory(ies)	Bermuda
Contract Holder Institution	Bermuda Zoological Society
Partner Institutions	Bermuda Institute of Ocean Sciences
Grant Value	£169,897
Start/end date of project	April 1, 2013 – March 31, 2015
Project Leader	Dr. Gretchen Goodbody-Gringley
Project website	NA
Report author and date	Dr. Gretchen Goodbody-Gringley

1 Project Overview

Located 32°N, 64°W, Bermuda's sub-tropical coral reefs represent the northernmost reef system in the Atlantic (see Map). The shallow rim reefs of this pseudo-atoll encircle the platform, dropping quickly to deep mesophotic reefs. Shallow water coral cover in Bermuda ranks among the highest in the Caribbean with an estimated cover of 38.6% (Jackson et al 2014), making Bermuda an important location in which to study coral reef systems and overall reef resilience.

Since 2004, invasive lionfish have successfully established populations throughout the Caribbean Sea, the Gulf of Mexico, the Western Atlantic, and the north coast of South America. Lionfish are now ubiquitous throughout these regions, having established themselves in a variety of marine habitats, consuming large quantities of small and juvenile fishes and reef invertebrates. Lionfish populations in the Atlantic have reached densities far exceeding those found in their native habitats, which will likely affect the biodiversity and community structure of reef fish communities and could impose significant ecosystem change. The Bermuda Invasive Lionfish Control Initiative aimed to increase knowledge of the invasive lionfish population in Bermuda waters in order to improve the management of this invasive species, with the aim of protecting the biodiversity and ecosystem function of reef systems around Bermuda.

This project worked to gather data on lionfish abundance and distribution that are critical for developing targeted removal plans. Additionally, significant advances were made in developing a lionfish-specific trap for commercial fishers to facilitate large-scale, long-term removal of this species from deeper waters in order to reduce the population and its impact. Furthermore, feeding ecology, reproductive ecology and recruitment rates were analysed to determine the impact of the population on the local environment and estimate levels of future lionfish recruitment, which will contribute to the management plan for long-term control of this invasive population.

Understanding the extent of the invasion and its effects on local fish populations has tangible applications for multiple stakeholders, including both environmental and commercial sectors. Furthermore, development of a lionfish-specific trap will increase efficiency of control programs while involving commercial fisherman in conserving their economic resource.

Overall, the Bermuda Invasive Lionfish Control Initiative project was designed to generate key data required for the implementation of the Bermuda Lionfish Control Plan developed by the Bermuda Lionfish Taskforce. This plan provides strategies for government and other stakeholder efforts to control the lionfish population at a level that will mitigate the long-term impact of this invasive species on native fish, reef communities, the island's economy and public health.

2 Project Achievements

2.1 Outcome

The overall purpose of this project was to gather data on lionfish abundance and distribution that are critical for developing targeted removal plans, and develop a lionfish-specific trap for commercial fishers to facilitate the large-scale, long-term removal of this species from deeper waters, thereby reducing the population and its impact. To that end we feel we have made significant strides towards this goal throughout the course of the project.

We have made substantial progress towards the assessment of lionfish population density and distribution (Output 1). Over the course of the project we have conducted over 75 surveys of lionfish and prey fish at reefs across the platform ranging in depth from 10m to 60m. The results of these surveys are striking, showing significant increases in lionfish densities with increasing depth (Fig. 1). The highest densities were found at our deepest sites, which had a mean density of 297 lionfish per hectare, with the highest density at one site exceeding 1,100 lionfish per hectare. This estimate derives from a dense but very localized aggregation site, referred to as a “hotspot”. The Bermuda densities are among the highest recorded in the wider Caribbean. The highest densities recorded elsewhere in the Caribbean are in the Bahamas where an average density of 390 lionfish per hectare was recorded. These data indicate that the invasive lionfish has a well-established population on deep reefs in Bermuda. However, the low densities found on shallow reef sites may reflect the overall health of Bermuda's reef as a buffer to invasion and provides hope that the lionfish population and its impacts on reef biodiversity in Bermuda could potentially be managed. Interestingly, a large amount of variation exists among the deep reef survey locations, with large aggregations of lionfish found at specific locations at the extreme eastern and western ends of the reef platform (Fig. 2). The “hotspots” identified through this project will guide management and control efforts, which can now focus on specific regions for removal that will have the greatest impact.

An important result from our site surveys was the relative absence of juvenile lionfish; we only found six fish less then 180 cm TL, the size at which females become reproductively active. Additional data from culling programmes has provided some insight to potential recruitment sites, but has not revealed any patterns in habitat type within Bermuda's reef platform that may be facilitating recruitment. Likewise, we failed to detect lionfish larvae with light traps, although we were not able to conduct as many light trap deployments as anticipated. It remains an open question as to the pattern of lionfish recruitment that must be driving the high adult densities we have measured.

Significant advances have been made towards development of a lionfish-specific trap to be used by Bermuda's commercial fishermen (Output 2). Using Bermuda's standard commercial lobster trap as a starting point, the goals were to increase lionfish catch, reduce lobster catch so that the traps could be used during the closed lobster breeding season, and maintain low bycatch of other finfish species. A variety of funnel types and deployment protocols were tested, and a modified version of the wire lobster funnel constrained by a 7" black ring produced the best results across the three criteria, followed by double square plastic top-loading funnels (Table 1). It was also clear that catches were greatly influenced by the density of lionfish in the surrounding area. To this end, mapping lionfish distribution patterns is critical to the success of trapping efforts. The Department of Environmental Protection is continuing to test the two best designs as well as an additional top-loading funnel design. Based on the success to date, additional funding has been secured to cover the cost of having three local fishermen operate traps with the best funnel designs in summer 2015.

Table 1. Average catch (CPUE) of lionfish, lobster and other finfish for the various funnel configurations

Funnel Type	***7" ring***	***Indented rectangle***	***Side rectangle***	***Two top funnels***
Total number of hauls	26	15	15	12
Mean lionfish catch	3.4	0.5	0.1	1.7
Mean lobster catch	2.0	0.0	0.0	0.1
Mean finfish catch	2.4	0.9	0.1	0.3

Considerable effort has been invested in increasing our understanding of lionfish ecology and their impact on reef communities (Output 3). Through the analysis of stomach contents, we have identified 28 different prey items by species, including 16 teleost fish and 12 invertebrates. However, we expect this is an underestimate as many items could not be identified due to the extent of digestion. With that in mind, we will continue with this work by attempting to genetically identify digested items. Teleost fish represent 46.3% of the lionfish diet by occurrence (frequency, %F), 53.0% by number (%N), and 69.2% by volume (%V). Similarly, invertebrates represent 46.1%F, but make a lesser contribution otherwise, comprising 42.3%N and 26.3%V. Of the invertebrates, shrimp represent 29.4%F, 25.4%N, and 18.8%V, lobsters comprise 8.5%F, 10.3%N, and 1.6%V, crab comprise 7.6%F, 6.1%N, and 5.0%V, while octopus contribute 0.4%F, 0.3%N, and 0.9%V. Unidentified items account for 10.8%F, 4.7%N, and 4.5%V. In total, 25.6% of stomachs were empty, primarily due to stomach eversion caused by barotrauma and the regurgitation of prey following capture. The single most common animal found within the diet of lionfish is the red night shrimp (*Cinetorhynchus rigens*), which represents 12.5%F, 11.3%N, and 16.9%V. As mentioned above, this is also likely underestimated as many shrimp could not be identified to the species level because of the extent of digestion.

A comparison of our survey data and stomach content analysis suggests the feeding habits of lionfish changes with depth based upon prey availability. At the deeper sites, Atlantic creolefish (*Paranthias furcifer)* and squat lobsters (*Munida simplex*, not included in our visual prey surveys) are the most abundant prey items. It is worth noting that Bermuda chromis (*Chromis bermudae*) and sunshine fish (*Chromis insolata*) were not identified in the stomach contents of lionfish, despite being the second and third most abundant prey fish at deep sites. At our shallowest sites, bluehead and yellowhead wrasse (*Thalassoma bifasciatum* and *Halichoeres garnoti*, respectively) were the most common teleost prey items. At these same sites, swimming crabs (*Portunid* spp.) made an equal contribution to the diet of lionfish as these two species, but all were found four-times less frequently compared to the red night shrimp.

Results from the stable isotope analysis suggest lionfish are a top predator with a broad resource base within the food web consisting of diverse and numerous benthic and demersal species. It is evident that they feed upon resources derived in both algae-dominated (i.e. inshore) and plankton-dominated systems (i.e. offshore). Furthermore, the data suggests an overlap of resource use between lionfish and juvenile dusky sharks (*Carcharhinus obscurus*). It also appears that lionfish captured at deeper sites are feeding at lower trophic levels from sources likely derived from plankton (Fig. 3). There was no apparent ontogenetic shift in trophic level ($\delta^{15}N$) or resource use ($\delta^{13}C$). Based upon these results, we are expanding our analysis to include multiple prey and competitor species to provide a more complete picture of the ecological interactions within the lionfish food web.

The data collected indicate that our approaches will provide the information necessary to achieve the project's purpose; however, some analyses and dissemination will need to occur after the project ends. Trapping trials and inshore juvenile lionfish surveys are continuing. Finally, our survey results indicate that continuous culling effort is needed to manage and control the population and thus this effort will need to be on going. To ensure that all project goals are met, we will be seeking additional funding to extend our project.

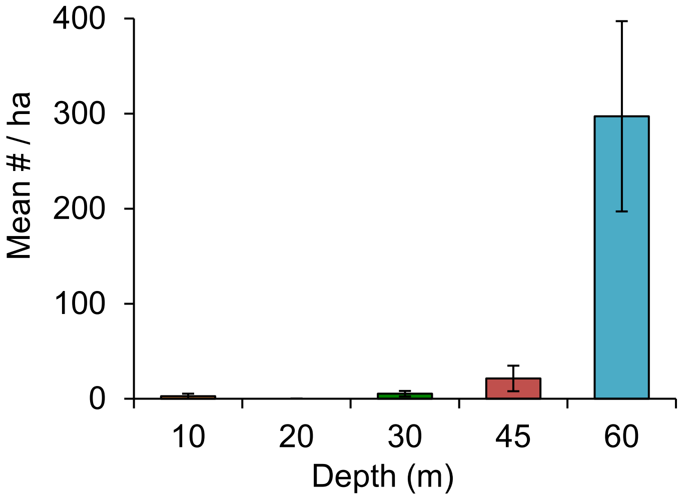

Fig. 1. Mean abundance of lionfish (#lionfish / hectare) at 10m, 20m, 30m, 45m, and 60m depths across Bermuda (n=12-15 sites per depth). Significantly higher densities were found at 45m compared to shallower depths, and at 60m compared to all other depths ($p<0.001$; ANOVA).

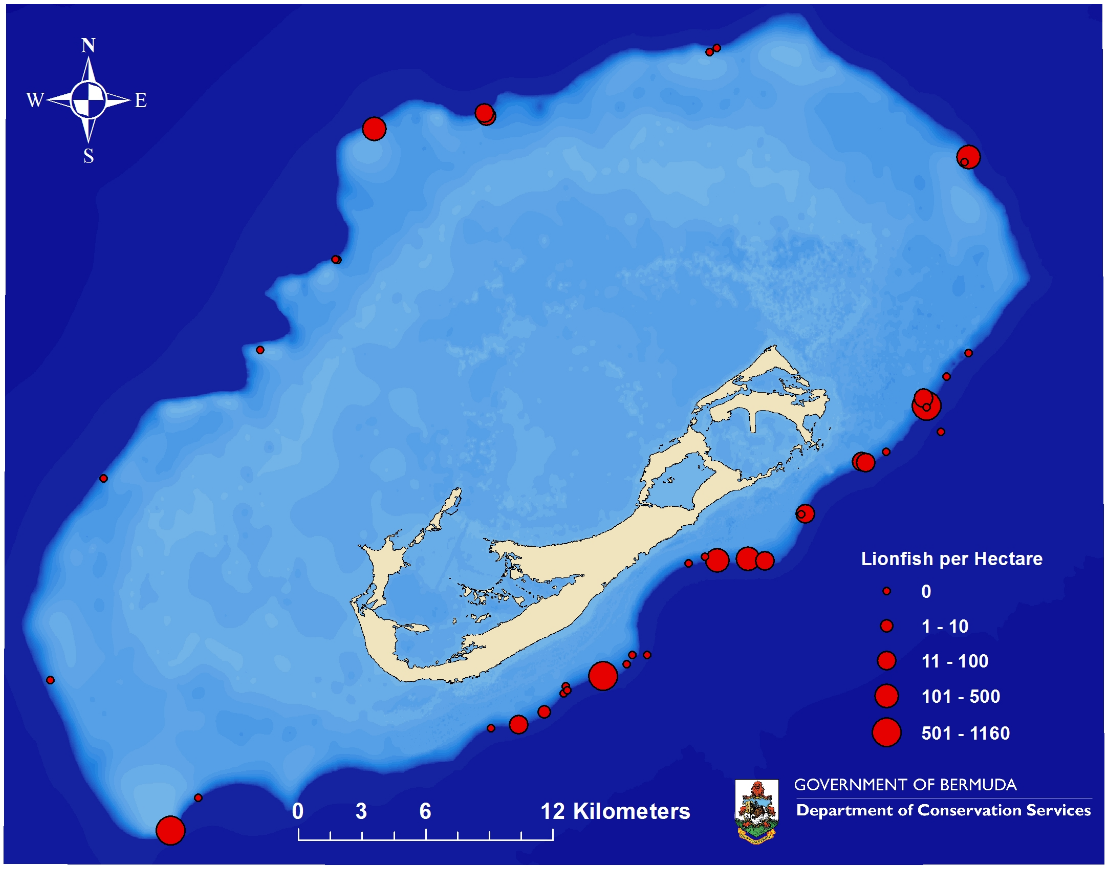

Fig. 2. Map of lionfish densities across the Bermuda platform from 45 to 60m. Contributing data include diver-led visual surveys and drop camera surveys. The size of each circle represents the relative density of lionfish per hectare, where a larger circle indicates denser aggregations of lionfish.

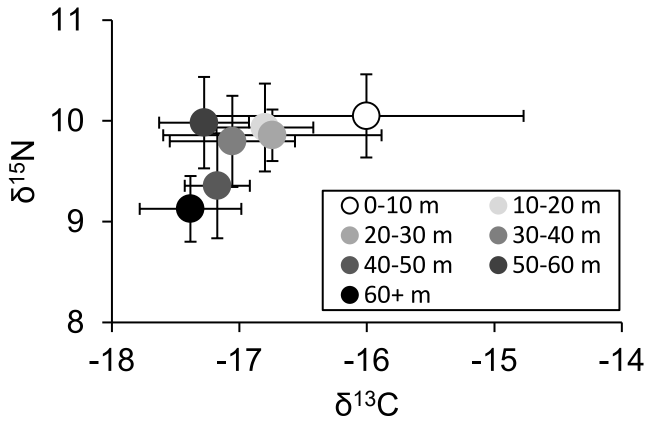

Fig. 3. $\delta^{13}C$ and $\delta^{15}N$ bi-plot of invasive lionfish separated into 10-meter depth increments. Values are mean ± standard deviation. With the exception of the 40-50m bin, for which there were limited samples, lionfish found at deeper sites appear to use offshore resources, likely derived from plankton.

One of the main outcomes of this project is the identification of areas with high abundances of lionfish that will be made a priority for removal. See section 2.1 for details. These data will help guide management decisions and control efforts. Thus the results of this project have changed our perception of the amount of effort that is required to manage the invasive population. Future control efforts must expand upon previous shallow water culling programs to include deep reefs. Likewise, continued monitoring of lionfish densities across the depth range will remain a key priority in order to determine the efficacy of control effort and impact of the invasive population.

Another key outcome is the development of the lionfish trap and the involvement of the commercial fishing community in controlling the invasive population. This is important because the lionfish are concentrated in deeper waters (30m - 60m) that are inaccessible to most cullers. A trap that can effectively target lionfish without unduly impacting other species makes a targeted commercial scale fishery possible, and this will help facilitate the long term control of this invasive species.

Additionally, prey fish surveys have increased our understanding of biodiversity and species distributions across the Bermuda platform. Furthermore, gut content and stable isotope analyses have increased our understanding of the potential impact of lionfish to this biodiversity. Results of these data indicate that our surveys of prey populations going forward must include benthic invertebrates as well as fishes. Likewise, we will incorporate barcoding technology to aid in future gut content identification.

The PIs have been involved with the Lionfish Taskforce and have been able to update and inform the group of the results on a frequent basis. The Taskforce has responded to this information and coordinated with another local NGO, the Ocean Support Foundation, to stimulate lionfish culling activity. Over 600 culling licenses have been issued since 2012. A consistent outreach effort has allowed more people to understand the issues and be more willing to consume lionfish. The growth in the appreciation of the economic value of lionfish has allowed the Department of Environmental Protection to affirm the need for the use of lionfish-specific traps and this is supported by the Marine Resources Board. In addition, the Darwin+ grant and the work done under its auspices have led to increased awareness amongst both the general public and high level government decision-makers of the importance of controlling the lionfish invasion.

A determination of the patterns of distribution of lionfish along the deeper contours of the Bermuda reef system (30-60m) will facilitate the use of lionfish-specific traps by local commercial fishermen in the future. We believe that targeting of known “hotspots” and the avoidance of de-pauperate reef area will focus the fishing effort and hopefully provide sufficient rewards for the fishers. The explicit locations of the hot spots will be provided to participating fishers by the Dept. of Environmental Protection (Fig 2).

The analyses of the lionfish prey choices have shown that in Bermuda the lionfish have a broader diet than reported from other Caribbean locations. We can conclude that the potential impact of these fishes, particularly on shallow reefs where lionfish densities remain very low, may not be exceptional. On deeper reefs the lionfish may be simply replacing other reef predators (serranids and lutjanids) that have been fished intensively. A caveat is that the densities of lionfish can be exceptional at "hotspots" and this characteristic is not a feature of other reef predators. Thus, the impact of lionfish prey consumption may be significant but perhaps only at localized sites.

Overall this project resulted in an immense amount of data that will be used to plan future lionfish management and control efforts. Such comprehensive data sets are rarely available and will provide invaluable guidance to decision makers. These results therefore represent an important contribution to the control of invasive lionfish and thus to the conservation of biodiversity in Bermuda. The lessons learned in Bermuda will also inform other UKOTs dealing with invasive lionfish.

2.2 Outputs

Output 1: Estimates of species abundance and distribution

A total of 85 surveys were conducted for this project. These include initial surveys at 15 sites at 10m, 15 sites at 20m, 15 sites at 30m, 15 sites at 45m, and 12 sites at 60m. Repeated surveys were conducted at 10 of the sites at 30m and 3 of the sites at 60m. Additionally, 17 drop camera surveys have been completed, with work ongoing using Department of Environmental Protection resources. We now have a clear understanding of population densities and distributions of lionfish across the Bermuda platform. However, the absence of data in regard to the distribution of juvenile lionfish remains as a significant gap of knowledge. The information gained from these surveys will contribute to several scientific publications and a report submitted to the Bermuda Lionfish Taskforce to be shared with local stakeholders.

Output 2: Lionfish specific trap to control proliferation

Following camera observations of lionfish interacting with standard commercial lobster traps, three traditional fish pot funnel designs, a modified version of the standard wire lobster funnel, and a top-loading funnel design were tested, along with a number of different deployment protocols. The modified wire lobster funnel constrained by a 7" black ring produced the best results across these three criteria, followed by the square plastic top-loading funnels. It became apparent that in the relatively flat habitat at 60m the structure of the trap was an attractant in itself, meaning that bait was less important. Avoiding the use of dead baits helped reduce the catch of lobsters and other finfish. It was also clear that catches were greatly influenced by the density of lionfish in the surrounding area. To this end, mapping lionfish distribution is critical to the success of trapping efforts. The Go Pro cameras and deepwater housings purchased using the Darwin+ grant provided invaluable insights during this phase of trap development, and they are still being used as the Department of Environmental Protection continues testing the two best designs as well as an additional top-loading funnel design. Based on the success to date, additional funding has been secured to cover the cost of having three local fishermen operate traps with the best funnel designs over the coming summer.

Output 3: Assessment of present impact and model of potential future impacts

During each of the 85 dives conducted for lionfish surveys, 6 prey fish surveys were also conducted, identifying and counting all fishes <15cm TL encountered. These surveys collected baseline data of fish diversity and distribution along a depth gradient and compared prey fish abundances to lionfish abundances. Interestingly, we found no correlation between lionfish and prey fish densities. However, this result is difficult to interpret as these data represent a baseline in densities that could change over time. This is particularly true for the poorly studied deep reef sites (45m and 60m), where these surveys document high levels of diversity and abundance of fishes not previously described at these depths. Using gut content analyses we found that lionfish preferentially target small-bodied fishes in shallow zones but may switch to alternate species with increasing depth. We also found an increasing reliance on non-fish species as prey sources, such as crustaceans and other benthic invertebrates, highlighting the importance of expanding our impact surveys to include benthic organisms. Stable isotope analyses corroborate these results and indicate that lionfish are categorized as generalist meso-predators.

Based on analyses of gonads, lionfish are actively reproducing in Bermuda. However, they appear to be less fecund than individuals in more southerly locations, with reproduction possibly hindered during the winter months in Bermuda. Based upon the gonadosomatic index (i.e. GSI), it appears reproductive activity may increase through the summer, following an increase in sea-surface temperature (Fig. 4). Our data also suggests a possible peak of activity in July, then another in October (Fig. 4). This is corroborated by the histological and macroscopic examination of lionfish gonads. These latter examinations suggest lionfish are not reproducing during the winter in Bermuda, which may help to explain the absence of juveniles and the apparently slow growth in Bermuda's lionfish population, relative to other locations. Additionally, light trap deployments failed to catch any larval lionfish, suggesting that the proportion of juvenile lionfish produced locally may be low compared to that which arrives from other regions. It is also possible that there have been weak cohorts through the period of our study. Furthermore, few juvenile fishes were found to contribute to the genetic analyses. A total of 75 individuals were genotyped and the sequences are currently being analyzed for population genetics and migratory patterns among deep reefs. While we have found reproductively active individuals at all depths, our inability to capture lionfish larvae or many immature individuals raises questions regarding the extent to which Bermuda's population is self-supporting. Taken together, these data suggest that the local lionfish population may be seeded primarily by populations at other invaded regions, such at the east coast of the United States and the Bahamas. However, the local seasonal reproduction occurring across Bermuda's platform likely contributes to some extent to population maintenance.

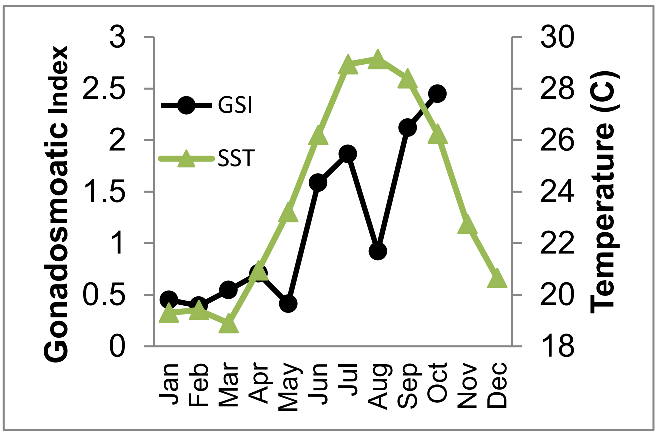

Fig. 4. Plot of the gonadosomatic index (GSI) of female lionfish with and mean sea-surface temperature (SST) for 2013-2014, suggesting reproductive activity increases through the summer with SST and indicates two possible peaks of activity in July and October.

Based upon the examination of lionfish otoliths, we have aged Bermuda's population and successfully developed a von Bertalanffy Growth Curve (Fig. 5). The growth curve for Bermuda lionfish is similar to that of lionfish caught in the Cayman Islands and North Carolina. A comparison of growth between the three regions suggests that the maximum size of lionfish increases with latitude and that initial growth rates are also greater in the northern regions. Our analysis shows a maximum age of ten years and differential growth rates of males and females (Fig. 6). There was, however, no difference in growth between those lionfish caught in deep versus shallow habitats.

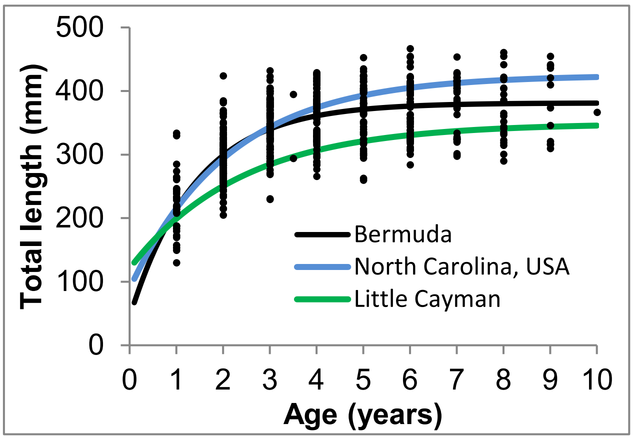

Fig. 5. A Von-Bertalanffy Growth Curve fit to our data (black circles and line) as well as curves from North Carolina and Little Cayman.

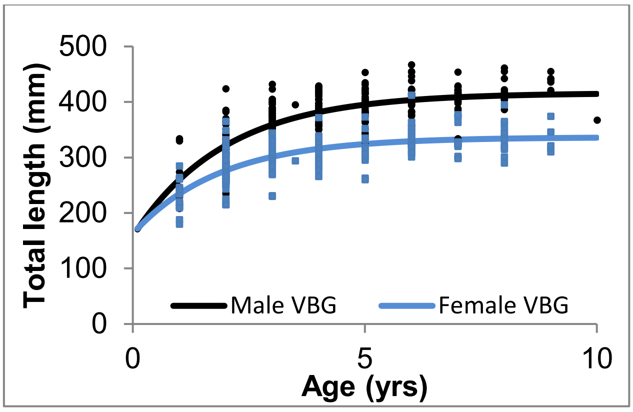

Fig. 6 Von-Bertalanffy Growth Curves fit to our data indicating differential growth rates for males and females, as well as different maximum sizes.

Output 4: Dissemination and application of results

To date all key data collection is complete, however some analyses such as building population dynamic models and population genetics analyses will continue. Following initial indications of aggregations of lionfish at "hotspots", a total of 12 data loggers were purchased by the Bermuda Lionfish Taskforce to be deployed in 2015 by the research team in order to further explore physical attributes of these habitats that may promote recruitment or aggregation of lionfish at specific locations. Identification of these hotspots was also shared with permitted cullers through the Ocean Support Foundation and Bermuda Lionfish Taskforce webpages (www.lionfish.bm), which provides a distribution map identifying locations where lionfish have been found and should be targeted for removal efforts.

Results of this work and dissemination of our efforts have been presented in multiple forums. For example, a special informational dinner was held at a local golf club, at which the research project was presented and a discussion was held on how to move forward with this issue. Likewise, presentations have been made to the local Rotary clubs in Bermuda, at multiple schools across the island, the Bermuda Underwater Exploration Institute, and the Bermuda Aquarium Museum and Zoo. Additionally, formal presentations have been made at several scientific conferences, including Gulf and Caribbean Fisheries Institute (GCFI) and Association of Marine Laboratories of the Caribbean, as well as presentations to the Bermuda Lionfish Taskforce. JMP shared results of the trap development work with other regional stakeholders at a fisheries workshop in Martinique in 2015 and will also participate in the upcoming lionfish management workshop to be held in conjunction with the GCFI meeting in November, 2015. WCE will be presenting results from the feeding ecology analysis at the American Fisheries Society meeting in August, 2015, and the results of our age/growth/reproduction investigations at GCFI in November, 2015. Dissemination has also occurred through local printed media sources, such as the Bermudian Magazine and the Royal Gazette, and in peer reviewed scientific publications (see references in Annex 2). Additional publications in the scientific literature are expected to result from this project as well as completion of WCE's Ph.D. dissertation.

Costs associated with diving to complete lionfish and prey fish surveys were more than originally expected. Likewise, coordination of divers' schedules to complete surveys limited the number of days that surveys could be conducted. Furthermore, use of the BZS boat, Endurance, proved to be logistically difficult in term of coordinating gear for conducting surveys, thus shallow surveys have been performed exclusively on BIOS small boats. However, the team worked well together to get as many surveys conducted as possible given these logistical constraints.

Following damage to the drop camera monitor screen during delivery, the proposed risk mitigation measure of using a borrowed drop camera proved logistically impossible and thus drop camera deployment was deferred to year 2 when a replacement screen was acquired. This resulted in a delay in data collection and analysis. We continue to work at no cost to finalize this component and incorporate the data into the overall lionfish distribution map.

Genetic analyses were to be completed with the help of an undergraduate student, however the student was unable to complete this work and thus sequencing was delayed until the final quarter of year 2. Again, we continue to work at no cost to analyse these data.

Very few to no juvenile lionfish have been encountered on the surveys or collected in light traps, limiting our ability to estimate rates of recruitment. Intensive efforts by cullers have also failed to detect significant numbers of juvenile lionfish around the reef platform. Snorkelers have not observed them in seagrass beds or within Bermuda's limited mangroves.

2.3 Sustainability and Legacy

Monitoring and culling

Our survey results indicate that continuous culling effort is needed to manage and control the population and thus this effort will need to be on-going. Furthermore, future control efforts must expand upon previous shallow water culling programs to include deep reefs. Likewise, continued monitoring of lionfish densities across the depth range will remain a key priority in order to determine the efficacy of control effort and impact of the invasive population. Specifically, it is imperative to continue monitoring densities and distributions of lionfish at the deeper reef sites in order to understand (1) if the invasive population is still growing; (2) if size demographics are changing as a measure of reproductive capabilities and recruitment; (3) if there are seasonal patterns of distribution; and (4) how preyfish densities are affected by the invasion. Only through continued monitoring can we truly assess the state of the invasion and its overall impacts on Bermuda's reef system. To that end, we will seek funding from a variety of sources to ensure continued monitoring and culling on these deep reefs.

Trapping program

Based on the success to date, additional funding has been secured to cover the cost of having three local fishermen operate traps with the best funnel designs over the coming summer. Additionally, the Go Pro cameras and deepwater housings purchased using the Darwin+ grant provided invaluable insights during this phase of trap development, and they are still being used as the Department of Environmental Protection continues testing the two best designs as well as an additional top-loading funnel design. Thus the work on developing a lionfish specific trap is ongoing and will continue pending available resources.

Project staff and resources

Several staff members were partially funded through this grant for their salaries. Specifically, GGG received roughly 3 months salary per project year as the lead PI. GGG is an Assistant Scientist at BIOS, which is a soft-money institution. The researcher is required to raise all the necessary funds through research grants and donations to cover salaries and all other costs. Without grant funding, GGG will be unable to contribute time towards continuing this project. As such, the team will be seeking additional funding to continue and expand this project. WCE was funded to complete his Ph.D. dissertation. He anticipates graduating in Spring 2016 and will be subsequently seeking funding for a postdoctoral position on research related to this project. AC works as technical diver on a consultancy basis and was supported on a per dive basis for this project. If additional funds are acquired he can be hired again in the same capacity. JP and SRS are funded by the Bermuda Government and will continue their roles in research related to this project.

3 Project Stakeholders

The project PIs were directly involved with the Lionfish Taskforce formation, which was contemporaneous with the start of this research project. The taskforce is representative of diverse stakeholder groups (divers, dive companies, spearfishers). We shared the ideas for our study with the Taskforce. Our project relied on information from these stakeholder groups to inform our decisions on some of the sampling locations, because of their local knowledge of lionfish distribution patterns. Commercial fishermen were involved in the various designs of the modified lobster trap funnels. There were some difficulties in the recruitment of commercial fishers due to concerns about favoritism or exclusion from an opportunity to participate in the experimental trap studies. However, information on the value of lionfish helped all commercial lobster fishermen profit from the increasing number of lionfish caught in their standard issue traps. Stakeholder groups were not included in decisions in regards to scientific procedures (survey methodology, sample processing and analysis).

4 Lessons learned

One of the greatest challenges to this project was working in a large collaborative team from a variety of sectors. As a group we worked extremely well together and combined resources and expertise to ensure the work was completed. Given our varied expertise, each partner was responsible for a different component of the project. This worked well as we are all individually motivated. However, one lesson learned moving forward is that a clear leader should be identified who is responsible for all data management, so that all data is compiled in one place. Our current management structure has resulted in each researcher managing their own data, which has limited communication of results. We probably needed to meet more frequently to review data but, as each PI had many other responsibilities, travel obligations etc., this outcome was perhaps inevitable as no-one was completely dedicated to just this project. Within our individual time constraints we believe we did perform effectively as a team and the reduced communication and data review did not greatly impact on the achievement of our field work goals. Our financial management structure worked very well and purchases and payments were well managed.

The objectives of this project were grand, and as such we required a team of individuals with very specific skill sets. Our team consisted of a population ecologist, fish ecologist, fisheries biologist, community ecologist, and a diving safety officer. In addition, two of the team members were trained to be technical decompression divers specifically for this work. All team members have extensive experience conducting field work and disseminating results. When certain components were difficult, outside expertise was sought, enabling accurate analyses and project completion. However, a postdoctoral researcher with modelling expertise would have greatly helped with final interpretation of data and such a collaborator has been identified to help as we develop our manuscript for submission to a peer-reviewed journal.

Overall, the project was well planned and properly addressed the problem. One of the main questions at the start of the project was the distribution of lionfish with depth. Anecdotal evidence had indicated that there were potential aggregations at depth, and the design of this experiment allowed us to locate these aggregations and identify deep reef hotspots. However, the timeframe was a bit too short for the amount of work we proposed as we only finished data collection at the end of March, 2015 and have the majority of writing still to complete. Likewise, we underestimated timeframe and the cost of completing fieldwork and molecular analyses. To overcome these shortcomings we were forced to reduce the total number of surveys completed and had to raise additional funds to complete the molecular work. As with any project, additional questions were raised as the project was underway, such as how to identify digested gut content and the absence of juvenile fish in the surveys. We are hoping to extend this work to continue our analysis of the impacts of the lionfish on Bermuda's reefs.

4.1 Monitoring and evaluation

Monitoring and evaluation took place through quarterly meetings with all partners and our financial officer. During these meeting we discussed progress and problems of each component of the project as well as future directions. Monitoring was also conducted on a continual basis by the Bermuda Lionfish Taskforce, which was updated on project progress regularly. The only major change to the project design was the reduction in survey locations, however, we feel that the amount of surveys completed provides a detailed description of the population distribution across the Bermuda platform. Thus, the reduction in survey sites did not impact the integrity of our experimental design. The final step in evaluation of this work will occur through the peer review process of publication in scientific journals. We expect a minimum of 3 scientific publications to result from this work.

4.2 Actions taken in response to annual report reviews

No action was required in response to the annual reports.

5 Darwin Identity

This project has received quite of bit of local publicity, being featured several times in the local newpaper, and speaking opportunities, and public events (see Annex 2). Within the community, residents who are interested and concerned about environmental issues are likely to be aware of this project. We hope that this awareness will increase the likelilhood of securing local funding to continue this work. Internationally, the project was presented at several scientific meetings in the form of lectures and posters. At all venues where a lecture or poster was presented, the Darwin Initiative logo was displayed and acknowledged as providing the funding support for this project. This project was distinct with a clear identity. In fact, we are referred to locally as the “Darwin Team”.

6 Finance and administration

6.1 Project expenditure

Project spend (indicative) since last annual report	2015/16 Grant (£)	2015/16 Total actual Darwin Costs (£)	Variance %	Comments (please explain significant variances)
Staff costs				
Consultancy costs				
Overhead Costs				
Travel and subsistence				
Operating Costs				
Capital items				
Others				
TOTAL				

Staff employed (Name and position)	Cost (£)
Gretchen Goodbody Gringley, PI	
Corey Eddy, PhD candidate	
TOTAL	

Consultancy – description of breakdown of costs	Other items – cost (£)
Deep Dive Support (Boat, Tanks, Fuel) Technical Diver Support	
TOTAL	

Capital items – description	Capital items – cost (£)

Not Applicable	

Other items – description	Other items – cost (£)
Stable Isotope Study Materials DNA Microsatellite Study Materials Equipment for Deep Dive Surveys	
TOTAL	

6.2 Additional funds or in-kind contributions secured

Source of funding for project lifetime	Total (£)
Bermuda Lionfish Taskforce for genetics analysis in second year	
C. Eddy salary and travel over two years	
OSF in-kind volunteer divers over two years	
J Pitt salary over two years	
S R Smith salary over two years	
I D Walker salary over two years	
TOTAL	

Source of funding for additional work after project lifetime	Total (£)
Local corporate sponsorship (Lionfish Taskforce) to continue / expand trapping work	
Atlantic Conservation Partnership internships (2) for juvenile lionfish surveys in 2015	
TOTAL	

6.3 Value for Money

Funds requested were realistic for the costs of operating in Bermuda, where everything must be shipped into the island and is taxed at entry. Salary support requested for partners associated with BIOS is at the low end of local salary brackets and therefore provides excellent value for money in the Bermuda context. A significant proportion of project cost was covered by in kind support from multiple channels. Salary support for 14 months for WC Eddy was provided through an NSF Graduate Research Fellowship stipend (£), for one month per year for J Pitt by the Department of Environmental Protection (£for two years), and for 3 weeks for SR Smith by BAMZ (£for two years). ID Walker of BAMZ contributed about 1 week of work each year for financial oversight of the project for the Bermuda Zoological Society (BZS). In addition all banking fees and exchange rate losses were covered by the BZS. Deep dive support was provided by OSF volunteers. Hiring divers with equivalent training and experience at a daily rate would have cost approximately £Where possible, items imported for the project or sent overseas for analysis were hand carried to save on shipping costs.

Annex 1 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)	(ii) 1 (WCE)
2	Number of (i) people in UKOTs; and (ii) other people receiving other forms of long-term (>1yr) training not leading to formal qualification	(i) 2 (GGG, WCE)
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 (ii) 2
3b	Number of training weeks (i) in UKOTs; (ii) outside UKOTs not leading to formal qualification	
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	
Research Measures		
6	Number of species/habitat management plans/ strategies (or action plans) produced for/by Governments, public authorities or other implementing agencies in the UKOTs	1
7	Number of formal documents produced to assist work in UKOTs related to species identification, classification and recording.	
8a	Number of papers published or accepted for publication in peer reviewed journals written by (i) UKOT authors; and (ii) other authors	(i)1 (ii)1
8b	Number of papers published or accepted for publication elsewhere written by (i) UKOT authors; and (ii) other authors	
9b	Number of computer-based databases enhanced (containing species/genetic information). Were these databases made available for use by UKOTs?	1, not available yet. Will be when Natural History database is completed this year
9a	Number of species reference collections established. Were these collections handed over to UKOTs?	
9b	Number of species reference collections enhanced. Were these collections handed over	1, some gut contents stored in the Bermuda Natural History Museum

Code	Description	Totals (plus additional detail as required)
	to UKOTs?	
Dissemination Measures		
14a	Number of conferences/seminars/workshops/stakeholder meetings organised to present/disseminate findings from UKOT's Darwin project work	4 Lionfish Taskforce meetings 1 meeting with local fishermen (more are planned)
14b	Number of conferences/seminars/ workshops/stakeholder meetings attended at which findings from the Darwin Plus project work will be presented/ disseminated	4 attended and 2 forthcoming
Physical Measures		
20	Estimated value (£s) of physical assets handed over to UKOT(s)	
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 2 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. contact address, website)
Scientific Journal	Use of mesophotic coral ecosystems (MCEs) by invasive western Atlantic and native Indo-Pacific lionfish. Andradi-Brown, DA, et al. In Review	Honduras	UK	Male	Coral Reefs	Currently in revision
Scientific Journal	Upper and lower mesophotic coral reef fish communities evaluated by underwater visual census in the Caribbean. Pinheiro, H, Goodbody-Gringley, G, Jessup, EM, Sheperd, B, Chequer, AD, Rocha, LA	Brazil	US	Male	Coral Reefs	Currently in revision
Published Abstract	Distribution and abundance of the invasive lionfish along a depth gradient in Bermuda:	US	US	Male	AMLC, Curacao	Abstracts available in late 2015 from: http://www.amlc-carib.org/meetings/2015.html

	identification of deep reef “hotspots”. Eddy, C., Smith, S.R., Pitt, J.M., Chequer, A.D., and Goodbody-Gringley, G., 2015					
Published Extended Abstract	The feeding ecology of invasive lionfish in Bermuda. Eddy, C, Pitt, J, Smith, SR, Goodbody-Gringley, G, Chequer, A, Bernal, D, 2014	US	US	Male	GCFI, Barbados	Abstract and link to pdf of extended abstract available from http://www.gcfi.org by November 2015
Published Extended Abstract	Trapping lionfish in Bermuda, Part II: Lessons learned to date. Pitt, J and Trott, T. 2014	BDA	BDA	Female	GCFI, Barbados	Abstract and link to pdf of extended abstract available from http://www.gcfi.org by November 2015
Published Extended Abstract	Preliminary analysis of lionfish (*Pterois volitans* and *P. miles*) populations in Bermuda. Eddy, C, Pitt, J, Smith, SR, Goodbody-Gringley, G, Gleason J, Bernal, D, 2013	US	US	Male	GCFI, Corpus Christi, TX, USA	Abstract and link to pdf of extended abstract at: http://www.gcfi.org/proceedings/proceedings/preliminary-analysis-lionfish-pterois-volitans-and-p-miles-populations-bermuda
Published Extended Abstract	Efforts to develop a lionfish-specific trap for use in Bermuda waters. Pitt, J and Trott, T. 2013	BDA	BDA	Female	GCFI, Corpus Christi, TX, USA	Abstract and link to pdf of extended abstract at: http://www.gcfi.org/proceedings/proceedings/efforts-develop-lionfish-specific-trap-use-bermuda-waters
Magazine	By diving deep, a	US	BDA	Female	The	http://www.thebermudian.com/66-

Article	BIOS scientist exposes lionfish invasion. 2015				Bermudian, Hamilton, BDA	myblog/home-grown-made-in-bermuda/1476-by-diving-deep-a-bios-scientist-exposes-lionfish-invasion
Press Release	Waging war on the Island's lionfish menace. Sarah Lagan. 2015	BDA	BDA	Female	Royal Gazette, Hamilton, BDA	http://www.royalgazette.com/article/20150320/NEWS07/150329986
Press Release	Lionfish: Controlling the Predator. Department of Environmental Protection. 2014	BDA	BDA		Royal Gazette, Hamilton, BDA	http://www.royalgazette.com/article/20140306/FEATURES02/140309821
Press Release	More resources needed for lionfish battle. Owain Johnston-Barnes. 2014	BDA	BDA	Male	Royal Gazette, Hamilton, BDA	http://www.royalgazette.com/article/20140320/NEWS07/140329937
Press Release	Lionfish tamers. Owain Johnston-Barnes. 2013	BDA	BDA	Male	Royal Gazette, Hamilton, BDA	http://www.royalgazette.com/article/20130531/NEWS/705309881

Annex 3 Darwin Contacts

Ref No	DPLUS001
Project Title	Bermuda Invasive Lionfish Control Initiative
Project Leader Details	
Name	Gretchen Goodbody-Gringley, PhD
Role within Darwin Project	Project Coordinator and Principal Investigator
Address	
Phone	
Fax/Skype	
Email	
Partner 1	
Name	Corey Eddy
Organisation	UMASS
Role within Darwin Project	Graduate Student Researcher
Address	
Fax/Skype	
Email	
Partner 2	
Name	Alexander Chequer
Organisation	Ocean Support Foundation
Role within Darwin Project	Field Operations Manager
Address	
Fax/Skype	
Email	
Partner 3	
Name	Joanna Pitt, Ph.D.
Organisation	Bermuda Government: Environmental Protection
Role within Darwin Project	Trap Development Lead Researcher
Address	
Fax/Skype	
Email	
Partner 4	
Name	Struan R. Smith, Ph.D.
Organisation	Bermuda Aquarium, Museum and Zoo
Role within Darwin Project	Project Oversight, Guidance, and Field Assistance
Address	
Fax/Skype	
Email	

Partner 5	
Name	Ian D. Walker, DVM
Organisation	Bermuda Aquarium, Museum and Zoo
Role within Darwin Project	Financial management
Address	
Fax/Skype	
Email	