Breaking Bad – 10 years into a projected 30 year weed eradication program on World Heritage Listed Lord Howe Island

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Summary The Lord Howe Island Weed Eradication Program is possibly one of the most ambitious island weed eradication programs on an inhabited island, in the South Pacific – if not globally – given the density, distribution and diversity of weed populations that were present on the island at the program's commencement.

The program aims to search all weed management blocks, at two year intervals to continue to deplete target weeds. Novel techniques to survey and eradicate weeds on inaccessible terrain have been employed.

Since program inception in 2004, in the first 10 year period, the number of weeds, of up to 25 species has reduced by 80% (all life stages) and matures by 90% comparing first and last, measured treatments across 1164 hectares. The top two weed species removed include cherry guava (*Psidium cattleyanum* Sabine var. *cattleyanum*) (Figures 1–3) and ground asparagus (*Asparagus aethiopicus* L.). Six weeds have been declared eradicated, however they were initially limited in occurrence. Over two million individual weeds have been removed over the ten year period at a cost of AUD $6.4 million.

For the broader dispersed species the program is in the 'active' eradication phase (Panetta 2007) with mature weeds still being removed, albeit at a significantly reduced rate than at commencement. The strong downward trend in weeds removed per weed block suggests that the program will reach the 'containment and monitoring' phase for widespread species within the next decade; given sustained investment and technical solutions for weeds on cliff lines. However, the duration and lead in time makes the program vulnerable to eradication fatigue.

Eradication is considered the optimum investment if the goal is to provide long term protection to Lord Howe Island World Heritage listed ecosystems from weed threat.

Keywords Eradication, grid search, helicopter lance spray, cherry guava, *Psidium cattleyanum*, weeds on islands.

INTRODUCTION

Lord Howe Island (LHI) is an isolated oceanic island in the Tasman Sea, located 780 km north-east of Sydney (31°33'29"S, 159°05'12"E), New South Wales (NSW), Australia. The main island and its associated offshore islands are known as the Lord Howe Island Group (LHIG) and were inscribed on the World Heritage List in 1982 in recognition of the Group's superlative natural landscapes and scenery, its rich terrestrial and marine biodiversity (UNESCO; see http://whc.unesco.org/en/list/186).

The main island is 11 km long and 0.6–2.8 km wide covering 1455 ha and rises to 875 m (Mt Gower). The island has 87% native vegetation cover with 75% of the LHIG protected in the Permanent Park Preserve (PPP), similar to a national park but managed by the Lord Howe Island Board (LHIB) under the *Lord Howe Island Act 1953*.

Prior to its discovery in 1788 and subsequent settlement in 1833, the LHIG remained isolated from human influences. The key threats to the biota of LHI are climate change, plant diseases, introduced pest animals and invasive weeds (Hutton and Auld 2004, DECC 2007).

The impact of cherry guava on island ecosystems is well reported (ISSG 2013) and the risk to LHI along with other invasive weeds was quantified through baseline weed density and distribution mapping across 460ha by Le Cussan (2002a,b, 2003a,b), which advised an island wide time driven (30 year) eradication program. The program commenced in 2004 based on methodology from Raoul Island, New Zealand.

Over 670 introduced plants have been recorded from LHI, mostly in the settlement. Of these, 270 have invasive characteristics and/or have naturalised (DECC 2007). The LHI Weed Management Strategy 2006 initially targeted 25 species for eradication based on risk and feasibility. Currently up to 68 are prioritised initially assessed by the NSW Department of Primary Industries (DPI) Weed Risk Management (WRM) criteria and declared noxious for LHI Authority under the NSW *Noxious Weeds Act 1993*, to allow an 'all tenure' management approach.

The LHI weed eradication program forms part of a multi species recovery plan (LHI Biodiversity Management Plan, DECC 2007), complementing a range of other eradication/restoration initiatives being implemented coincidently. Here, we report on the results, including setbacks and learnings in the first 10 years of a strategy to eradicate highly invasive weeds. Data

Figure 1. Cherry guava – a tasty food plant, native to South America was introduced to LHI in the late 1890s. As with many pacific islands, it has demonstrated to be serious ecosystem invader.

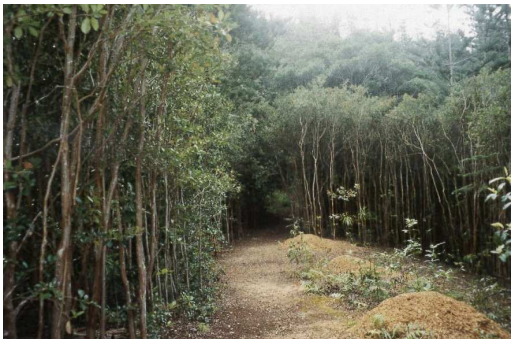

Figure 2. Cherry guava thicket from Stevens Reserve in the 1990s. Cherry guava can colonise intact to disturbed plant communities and persist as a seedling bank.

Figure 3. Outbreaks of cherry guava in the southern mountains have been detected and removed. These patches may be indicative of prior dispersal by feral pigs.

on cherry guava is provided as an example of what has been achieved. The output data for other major weeds follows similar trends to that of cherry guava (LHIB 2016). Future planned pest animal eradications and the importance of continued investment to trend target weeds to zero density/eradication for improved biodiversity outcomes on LHI is also discussed.

METHODS

To manage and eradicate weeds, the island is mapped into nine main landscape units – and further divided into 395 weed blocks corresponding to a Geographic Information System (GIS) and MS Access database (Figure 4). Weed blocks are physically marked on ground with blue marker tape or are aligned to lease boundaries. In the PPP blocks range from 0.38 to 62 hectares.

Weed searching is undertaken in a systematic grid pattern (including teams on ground, on rope or aerial search and control methods). On ground weed searching is demarked by string lines, used to retrace the grid edge. Team members must be evenly spaced so all land can be visually surveyed (average width of 5 m, decreasing with dense vegetation). All search effort is recorded on geographic positioning systems (GPS).

Target weeds in the PPP are subject to simultaneous search as most occupy similar habitats (to avoid

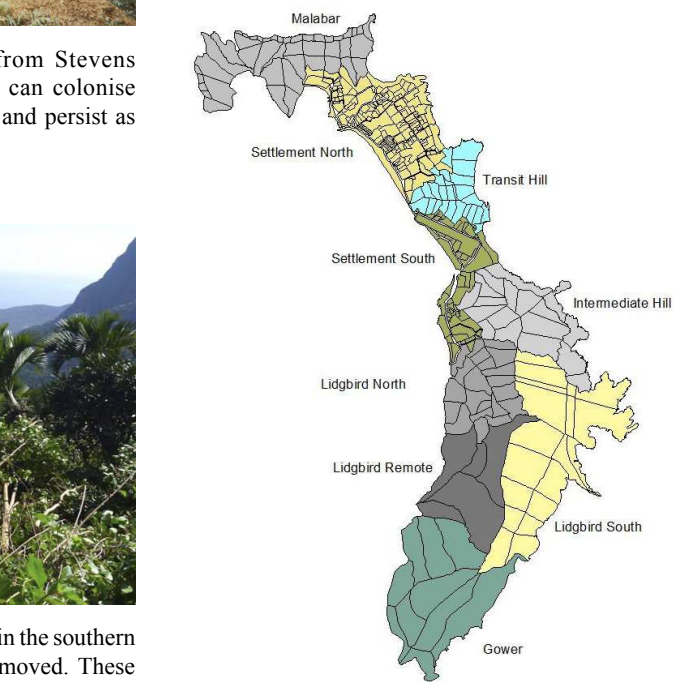

Figure 4. Landscape units and weed blocks – LHI.

replacing one weed with another), have comparable invasive capacity and environmental persistence (e.g. bird dispersed, persist in low light, form seedling banks, as opposed to weed seed banks). Several species with different reproductive traits are targeted during their active growth phase prior to fruiting.

About 80% of the island (1164 ha), where the target weeds are known to occur, is searched on ground. The search intervals of weed blocks should be no more than 24 months to treat at least 500 ha per year (approximately half of known weed habitats on island), based on reproductive biology in that target weeds will not mature within 24 months (from seed bank or juvenile). Three species, with limited distribution and/or shorter stage to reproductive maturity require annual search effort (bitou bush *Chrysanthemoides monilifera* (L.) Norlindh subsp. *rotundata* (DC) Norl., glory lily *Gloriosa supberba* L. and climbing asparagus *Asparagus plumosus* Baker, in migratory seabird nesting sites).

Isolated mature weed plants are marked in the field (Figure 5) and mapped on GPS and entered into the database as an 'INF' (for *infestation)*; to increase awareness of the need for repeated search efforts for new recruits. Marking isolated mature plants for focused searching is increasingly important as numbers reduce.

Figure 5. Flagging an 'INF' *Infestation* marker for an isolated 'outlier' mature cherry guava.

Most weed species are controlled by hand 'crowning out' or herbicide application – a mix of water with glyphosate and metsulfuron methyl for cut stump, scrape paint or foliar spray (Figure 6) (with additives of Pulse® or emulsified oil). Picloram gel is being trialled on blue passionflower – (*Passiflora caerula* L.). A helicopter with front mounted lance spray apparatus was developed to improve access to weeds on cliffs in 2015 (Figure 7). To accelerate search efforts in remote terrain in the southern mountains, teams are deployed by heli-winch over multiple days.

Figure 6. Dense widespread infestations of ground asparagus on Transit Hill were foliar sprayed with back packs. These dense infestations are now depleted. Grid search continues in accessible terrain, at least every 24 months, to remove any remaining matures and extirpate seed banks.

Figure 7. The helicopter mounted – forward lance spray apparatus provides simultaneous detection and treatment of outlier weeds (ground asparagus and bitou bush) on sheer cliffs. The spray pods have a 200 litre capacity. With the lance extending beyond the rotor blades, downwash is limited and foliar spray treatment is targeted.

Weed search effort is entered into Microsoft Access – 'the LHI Weeds Database' (hours of labour, numbers of weeds removed per weed plant life stage – seedling, juvenile or mature) per block. The database is used to monitor change in weed populations, hours of search effort per management unit, forecast treatment priorities and model trends.

To measure progress towards eradication after the first ten years, two methods were employed:

1. Scrutiny of the LHI weeds database on hectares treated, abundance of weeds removed and search effort.
2. Repeat landscape scale, weed density and distribution mapping as per J. Le Cussan (2002/03).

Mapping weed density and distribution **a**cross four landscape units (covering 460 ha) in 2002/3 measured the extent of weed threat across LHI. Repeat survey effort in 2013/14 replicated the method and extent of survey (Figure 8).

Parallel transects were set on a compass bearing (north–south or east-west) across each landscape unit. Transects were spaced 100 m apart and on each, at 20 m intervals, a circular sample plot four m in diameter (12.566 m^2) was surveyed for weeds. Target weeds were categorised according to height – juvenile (ground to knee height), shrub (knee to head height) and mature (above head).

A GPS waypoint was taken at each plot and corresponding field data downloaded into the Environmental Systems Research Institute (ESRI) Geographic Information System (GIS) package ArcView 3.3. Distribution and density maps were generated using Independent Distance Weighted (IDW) surface interpolation method in the ArcMap Spatial Analyst (ESRI) (Figure 3).

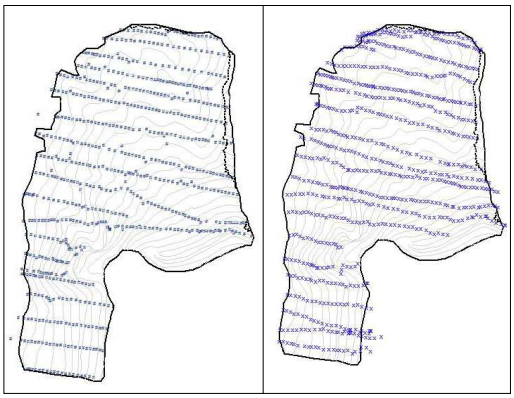

Figure 8. Lidgbird North weed mapping survey effort 2002–03 (left) and 2013–14 (right) with over 700 sample plots.

Figure 9. Numbers of weeds removed and area treated (ha) LHI 2005–2014.

RESULTS

The 2006 LHIWMS advised a minimum 24 month search interval which equates to near 500 ha yearly search effort. Figure 9 shows yearly search effort and the cumulative number of 25 weed species removed (all life stages).

Over the ten year period a total of 3941 ha have been searched, with the yearly effort from 214 to 603 ha. The extent of hectares searched per year reflects funding regimes. By year ten, weed blocks should have received five complete visits but have averaged 3.9 visits. However a strong downward trend is evident (all weeds). To deliver the preferred 24-month search frequency a yearly search target of 500 ha is required.

Outputs from the LHI Weed Database show the top ten weeds removed over ten years. Weed extent is based on detection in weed blocks (regardless of abundance) and sum of block size (Table 1).

The most abundant weed, cherry guava (first recorded on LHI in 1898), has been removed from 165 weed blocks across 1064 ha. The second most abundant weed, ground asparagus (first recorded in 1930), has been removed from 192 weed blocks across 1018 ha. Both species have island scale invasion potential and cumulative biodiversity impacts (occupying differing strata – ground and tree layer). Ground asparagus has 32 years less occupancy on LHI yet has established an invasion range on par with cherry guava.

Weed density mapping for landscape unit, Lidgbird North, indicates reductions in cherry guava at all life stages (Figure 10) with the map on the left comprising mostly mature plants and the map on the right mostly juvenile plants hidden amongst dense crofton weed (*Ageratina adenophora* Spreng.). These density changes are evidenced for most target weeds across island where repeat visitation has been measured.

Database outputs also show a strong downward trend in all life stages (Figure 11). Sum of weed mapping plot data of cherry guava from Lidgbird North, indicates reductions in all life stages up to 90% (Table 2). These figures compare to database outputs for the same landscape unit using number of plants removed from first and last treatment, which shows decline in mature plants of 96% (Table 3).

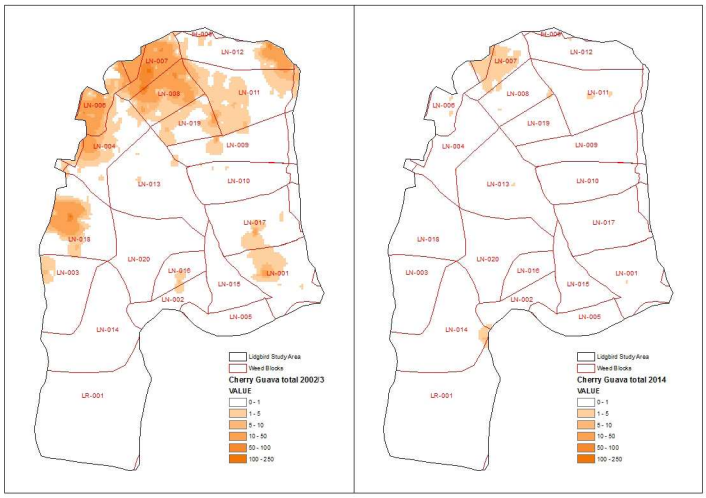

Figure 10. Lidgbird North – cherry guava density mapping 2002–03 (left) and 2013–14 (right); all life-stages.

Table 1. The top ten weeds removed over ten years.

Top 10 weeds removed (all life stages)	No.	Ha
Cherry guava (*Psidium cattleyanum* var. *cattleyanum*)	704,266	1064
Ground asparagus (*Asparagus aethiopicus*)	665,831	1018
Ochna (*Ochna serrulata* Hochst.)	458,168	648
Bridal creeper (*Asparagus asparagoides* (L.) Druce)	110,794	328
Sweet pittosporum (*Pittosporum undulatum* Vent.)	84,729	394
Climbing asparagus (*Asparagus plumosus* Baker)	53,840	260
Cotoneaster (*Cotoneaster glaucophyllus* Franch.)	26,211	266
Glory lily (*Gloriosa superba* L.)	13,655	55
Night jasmine (*Cestrum nocturnum* L.)	13,380	81
Bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata*)	3,459	215

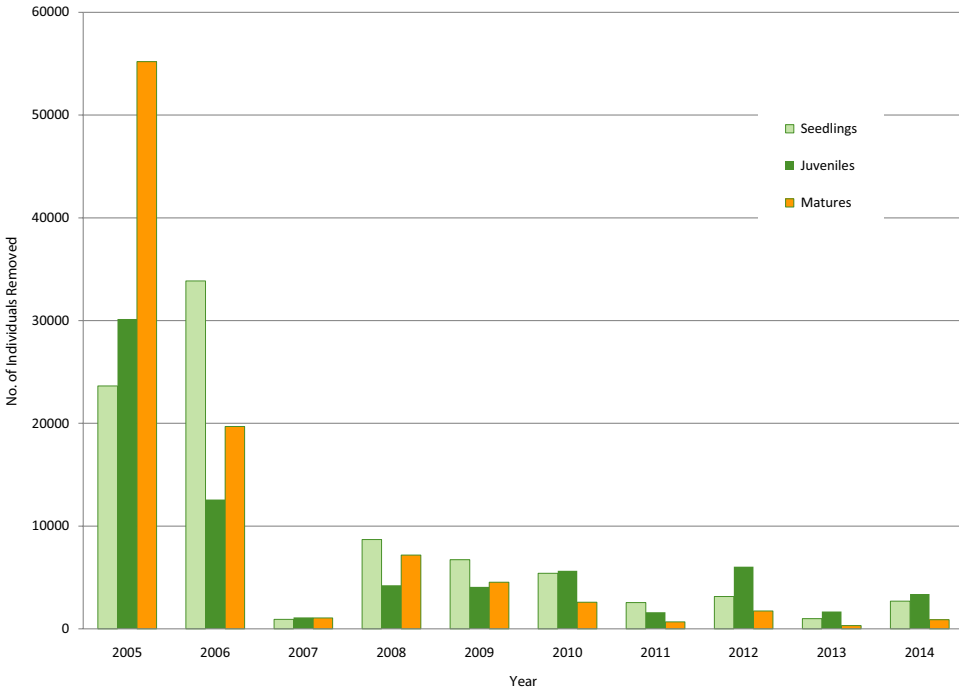

Figure 11. Cherry guava removed from Lidgbird North, 2005–14.

In 2014 mature cherry guava were represented by shrub sized plants (<2 m) with few inflorescence or buds compared to large fruit bearing trees (2–5 m) requiring chainsaw treatment which were common up to 2006 (Table 3).

Table 2. Cherry guava density mapping in 2002–03 and 2013–14 (Lidgbird North) sum of plots 0.92 ha.

Size Class	2002–03	2013–14	% reduced
Mature (over head)	1,008	7	99.3
Shrub (knee to head)	548	39	92.9
Juvenile (to knee)	385	149	62

Table 3. Cherry guavas removed comparing first and last treatment 2004–2015 LHI weeds database (Lidgbird North) 129 ha.

Treatment	First	Last	% reduced
Matures	78,277	3,005	96.2
Juvenile (immature)	45,340	11,074	76
Seedling (ankle high)	51,086	6,819	86.6

DISCUSSION

Species identified for eradication on LHI have been considered against criteria identified by Panetta and Timmins (2004) and LHI BMP (2007). For eradication to be successful it is critical to remove all mature weed plants, search and control at a rate to prevent reproduction, and continue removal of new recruits to extirpate/exhaust weed seed banks (Panetta 2007). Weed eradication programs often require ten years or more to achieve their objective and may require a period of gradual elimination to precede eradication (Holloran 2006).

Subject to adequate resourcing, the LHI weed eradication program fulfils these criteria by virtue of being surrounded by hundreds of kilometres of ocean with restrictions on plant importation, delimitation of area (the island), a grid search method that removes all life stages of target weeds each sweep and legislative powers that enable an all tenure approach. Furthermore the LHI weed data management systems provide a sound measurable basis for monitoring change in weed populations with effort, predicting future costs and priorities.

With a ten year lead in period out of a predicted 30 year program period, weeds have been depleted to such an extent that eradication capacity has significantly improved.

On first impressions when arriving at LHI it is difficult to conceive the previous extent and impact that ecosystem-modifying weeds imposed (Figure 12). Since program commencement, the number of weeds of up to 25 species has reduced by 80% (all life stages) and matures by 90% comparing first and last, measured treatments across 1024 hectares. Over 2 million weeds have been removed, with six species of limited distribution – declared eradicated. Another 36 are nearing eradication. In 2014 up to 45 exotic species of limited extent and mostly confined to the settlement were listed noxious to enable early intervention.

The program has had setbacks which are conceivable considering the prior sheer volume and distribution of the main weeds (Table 1) and the complexities of program roll out in an isolated environment with rugged cliff lines and resource limitations. Setbacks include:

- Failure of some control methods early in the program, requiring large areas to be re-treated;
- Fluctuation in funding impacting search regimes (3.9 return visits compared to a preferred 5 visits);
- Misreporting – now remedied with GPS;
- Lead in and growth of eradication ethic amongst all stakeholders; and
- Lead in phase for development of technology for weeds on steep and remote terrain.

The setbacks have provided valuable lessons to drive improvements and innovation such as the development of a front mounted heli lance sprayer enabling treatment of weeds from cliffs and heli winching teams to remote locations.

The LHIWMS 2006 predicted search effort would reduce post removal of mature plants. Analysis of effort per weed landscape unit comparing first and last treatment did not support this, except for the Transit Hill area (42% reduction in search time). This site exhibited widespread asparagus species that were initially treated by spraying and now only requires hand control.

Despite not receiving the targeted 24-month repeat treatment of weed blocks in the PPP, the program is still delivering a strong downward trend in weed density and distribution. The 24-month search interval is based on weed species reproductive traits and relies on effective on-ground grid search effort to remove all weeds from a block. Repeat treatments do detect previously missed mature plants, albeit at significantly reduced numbers. Ongoing island wide search effort is required to continue to remove remaining mature target weeds and extirpate weed seed banks to reach a containment and monitoring phase. Now is the time to 'Invest and Not Rest' (Jae De Clouett pers. comm. following a return visit from Little Barrier Island NZDOC weed eradication program).

The past ten year dataset is being analysed to model future abundance of weeds, management effort and timeframe for eradication (Baker *et al.* in prep).

As weeds have reduced on LHI a ground swell of 'eradication' awareness has grown through recognition of the human effort and visual change in the landscape. Community acceptance of delivering island eradication programs is growing, particularly where it can be shown to be beneficial to the island way of life (including tourism).

Figure 12. A view from the summit of Mt Gower. Pest plant and animal eradications on LHI are working to protect and improve the resilience of the islands World Heritage values. Photo: J. Shick.

The biodiversity benefits in continuing the program to eradicate highly invasive weeds on LHI are of global significance. Island comprise only 5% of the earth's surface, collectively they support 20% of all known bird, reptile and plant species and near half of all endangered species. Islands represent the greatest concentration of both biodiversity and species extinctions (http://www.islandconservation.org/why-islands/) – yet their isolation and limited size provides unique opportunities for conservation.

A draft LHI Weed Management Strategy 2016 has been prepared to drive the next decade of weed eradication focusing on:

- Prevention, early intervention (Weeds on Alert), eradication – immediate or suppression towards zero density and control;
- Removal of outlier incipient (nascent foci) weeds;
- Repeat weed search, minimum 500 ha y^{-1}
- New innovations – weed detector dogs, drones, Herbicide Ballistic Technology (Leary *et al.* 2013);
- Build and sustain local capacity;
- Seek committed project partners and secure long term – multi year funding;
- Apply island conservation management priorities including biosecurity measures.

It has been fortuitous this project was initiated well prior to the planned rodent eradication program. Rodents are significant seed and seedling predators (Auld and Hutton 2004). Weeds currently in low numbers and likely to spread post rodent eradication have been pre-emptively listed noxious and targeted for removal prior to rodent eradication.

The continuation of the program to eradicate invasive weeds will have complementary ecological benefits, building on other previous eradication programs on Lord Howe Island; pig *Sus scrofa* Linnaeus, cat *Felis cattus* Linnaeus and goat *Capra hircus* Linnaeus), current (African big-headed ant *Pheidole megacephala*) and future (rodent). The multi-species recovery actions being implemented by the LHIB are aimed at protecting and enhancing the islands unique biodiversity and World Heritage Values for the long term.

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