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Control of giant reed *Arundo donax* on Vila Franca do Campo Islet, Azores, Portugal

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SUMMARY

The non-native, invasive giant reed *Arundo donax* covers an estimated 30% of Vila Franca do Campo Islet (Azores). It blocks the entrance of Cory's shearwater *Calonetris diomedea borealis* nest burrows and out-competes threatened Azorean endemic flora. Three *A. donax* control methods were tested in 90, 1m^2 plots, and cost-effectiveness of each determined using a Simple Additive Weighting Model. The most effective control method was cutting and removal of reed stems followed by two glyphosate-based foliar herbicide applications (one in May and another in late October i.e. corresponding to before and after the Cory's shearwater breeding cycle). After one year, 92% of giant reed was eradicated at an estimated cost of €8,000 per hectare.

BACKGROUND

Giant reed *Arundo donax* is a perennial grass (Poaceae) native to Eastern Asia but long cultivated or invasive in the Mediterranean and Middle East (Polunin & Huxley 1987). It is a fast growing plant that can reach 6-8 m tall with stems up to 6 cm in diameter (Spencer *et al*. 2008, Silva *et al* 2008, Schafer 2005). Once established, it tends to form a continuous network of underground rhizomes that can reach 3 m depth (Coffman 2007). *A. donax* is considered one of the world's '100 worst plant invaders' (ISSG 2011) and one of the top 100 invasive species in Macaronesia (Silva *et al*. 2008).

The isolated Azores Archipelago consists of nine relatively young volcanic islands (Pena 1992). Since human colonization nearly 600 years ago, the islands have lost about 95% forest cover (Triantis *et al.* 2010). Introduced plants now comprise a large proportion of the Azores flora; of 1,002 vascular plant taxa present in the Azores today, only 31% are indigenous and/or endemic (Silva & Smith 2004). *A. donax* was intentionally introduced for hedging and to reduce soil erosion. Once established, it competes with and suppresses native plants, may choke stream channels, is extremely flammable (increasing the intensity of fires due to accumulated litter), and overall, causes drastic ecological changes (Silva *et al.* 2008, Coffman 2007, ISSG 2011). In the Azores, *A. donax* invasion has detrimentally affected at least 11 endemic vascular plant species and three seabird species (Cory's shearwater *Calonectris diomedea borealis*, common tern *Sterna hirundo* and roseate tern *Sterna dougallii*) considered of high level Conservation Status (Silva *et al.* 2008, Rodrigues *et al*. 2009, Silva *et al.* 2009).

The Azores are important breeding areas for seven pelagic bird species. After human settlement these were hunted for food and oil and their populations decreased drastically (Medeiros 1987), exacerbated by the introduction of several mammals that predated the birds or degraded their nesting habitat. On the Azores, breeding colonies of these species are now restricted to small islets or inaccessible cliffs free from introduced mammals (Monteiro *et al*. 1996). The most resilient is Cory's shearwater, with an estimated 75% of the world population breeding in the archipelago (azores.gov.pt 2011).

Despite the many *A. donax* control and eradication programs over the world, there are no efficient low-cost eradication methods specific to pelagic bird nesting habitat (Spencer *et al*. 2008, ISSG 2011, Freixas 2009). On islets and cliffs where control using heavy machinery is not possible, herbicide control may be employed but this may have negative impacts on non-target species (Spencer *et al*. 2008, Freixas 2009). Therefore, new sustainable control or eradication methods are required.

In 2009 a LIFE project "Safe Islands for Seabirds" (2009-2013) was initiated. The project is a feasibility study to evaluate the efficacy of controlling and eradicating invasive non-native animals and plants, and restoring natural vegetation (co-financed by the European Commission and the Azores Government; SPEA 2011). This paper presents the *A. donax* eradication methods trialed, outcomes and costs. The trials were adapted to take account of islet location, access constraints, weather conditions, and potential impacts on endemic plants and nesting Cory's shearwaters.

ACTION

Study area: Vila Franca do Campo Islet (VFCI) is located 1 km from Vila Franca do Campo off the southeast coast of São Miguel Island (37º42.30 N, 25°26.52 W). It is part of the Natural Park of São Miguel Island (Fig. 1). The islet has an area of about 7 ha and rises to an altitude of 62 m a.m.s.l. (Rodrigues *et al*. 2009).

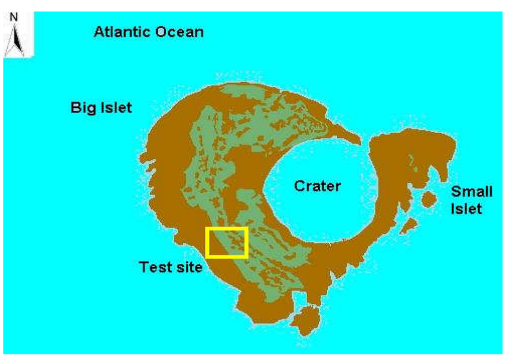

Figure 1. *A. donax* distribution (indicated in green) on Vila Franca do Campo Islet. The trial site is indicated by the yellow square.

It has no permanent human habitation but receives visitors to restricted areas from June to September. The native vegetation is still mainly intact, dominant species including Azorean fescue *Festuca petraea*, firetree *Myrica faya*, Azorean heather *Erica azorica* and Azorean spurge *Euphorbia azorica*. However 30% of vegetated areas comprise *A. donax* (Fig. 1) (Rodrigues *et al*. 2009, Morton *et al*. 1998, SPEA 2010). The islet is an important breeding site for Cory's shearwater and common tern (Rodrigues *et al*. 2009), two seabird species that are under threat on the archipelago mainly due to habitat loss and degradation.

Due to access constraints imposed by adverse weather and sea conditions, *A. donax* control on VFCI is usually only possible between March to mid-May and the last two weeks of October (after which as well as rough seas, the weather is usually too rainy for effective herbicide application). Access to VFCI is via boat from Vila Franca do Campo marina. The dock on the islet is small with transport of material and equipment limited to a small boat (capacity six passengers). Control application was timed to avoid detrimental impacts during the breeding season to Cory's shearwater, and to minimize adverse effects on breeding habitat and native flora. Control was only implemented on the top of the islet where nest density and the risk of burrows destruction through collapse by operators were low. Cory's shearwaters return to the islet at the end of February, egg-laying in burrows during late May to early June. Eggs hatch in mid-July (Granadeiro 1991) and chicks fledge in late October (Rodrigues *et al.* 2009).

Phenology of the native flora was an important consideration in governing *A. donax* eradication methods and timing of treatment applications. The endemic flora seeds from July to late September, with germination commencing in October (SPEA 2011).

Treatments: Based on these constraints and initial evaluations of methods reported in the literature, two different approaches to *A. donax* control were tested. The first was a 'traditional model' that consisted of cutting stems with biomass removal. The second approach, the 'integrated model' combined cutting of stems, biomass removal and foliar applications of glyphosate-based herbicide on resprouting shoots (ISSG 2011).

Stems were cut with a machete and the cut material removed by hand. Stem cutting was targeted to unblock entrances to Cory's shearwater burrows. Biomass removal is also important to clear space for planting native species (Azorean heather and firetree) and to improve conditions for germination of native plants.

Table 1. Summary of treatments and application dates.

Type of Model	Traditional Model	Integrated Model	Integrated Model
Treatments	**Treatment C**	**Treatment A**	**Treatment B**
Cut stems (April 2009)	Yes	Yes	Yes
1st spray (May)	No	Yes (5%)	Yes (5%)
2nd spray (October)	No	Yes (3%)	Yes (1.5%)
Number of replicates	30	30	30

To remove cut material from the islet is difficult and expensive, Therefore, once dry (dead), *A. donax* was used as matting to reduce soil erosion.

Foliar herbicide was applied 4-5 weeks after cutting when re-sprouted shoots were approximately 1 m height; this allowed a reduction in the amount of herbicide used opposed to spraying of uncut *A. donax* and a consequential decrease in the risk of foliar spray affecting non target species (ISSG 2011). The herbicide used was Roundup® Ultra with 360g/l of glyphosate. Other authors recommend concentrations of 1.5% to 6% for foliar application (ISSG 2011, Lawson *et al*. 2005). According to Spencer (2008) a solution of 3-5% of glyphosate has a good efficacy, so a 5% concentration was used in this trial. Herbicide was applied in appropriate weather conditions (low wind and no precipitation).

The first herbicide application in May was timed to prevent *A. donax* growing up and blocking entrances to Cory's shearwater burrows during the breeding season. A second application was made in October when *A. donax* begins to move photosynthate (sugars) into the underground rhizomes after flowering and just before winter dormancy (Lawson *et al*. 2005). Two concentrations were trialed: 1.5% and 3.0%. It was applied at lower concentrations than the spring application in order to try to reduce the cost (i.e. quantity of herbicide used) and to decrease possible detrimental impacts on germinating seeds of native plants.

The trial was conducted from March 2009 to March 2010. Three different treatments were developed. The traditional model (cut stems) was assigned 'treatment C' and compared *A. donax* response after cutting with the other treatments. The other treatments are integrated models (cut and subsequent foliar applications of 5% herbicide).

In addition to the first application of herbicide, treatment A received a second foliar application of 3% of herbicide solution and treatment B a second foliar application of 1.5% of herbicide solution. Treatments are summarised in Table 1.

Monitoring: Ninety 1m² plots (1 m apart in a 3 x 30 grid) were established to evaluate effectiveness of the eradication methods. Random placement of plots was not possible because of logistical problems. Treatments A, B and C were each tested in 30 different plots. Each strip of 30 plots had different treatment sequence in order to decrease any neighbour effect. These were: Strip 1: C, A and B; Strip 2; A, B and C; Strip 3: B, C and A. These treatment sequences followed the same pattern throughout each strip.

Effectiveness: It is difficult to assess death in *A. donax* due to the rhizomes underground that may still be alive. Therefore, treatment effectiveness was measured as the number of shoots resprouting after 1 year of control. All stems were counted in plots in four periods:

t0 - before the *A. donax* control was initiated (April 2009);
t1 - 4 weeks after cutting, but before any herbicide application (May 2009);
t2 - 5 months after the first herbicide application (October 2009);
t3 - 5 months after the second herbicide application (February 2010).

Due close proximity of sample plots (1 m apart), the herbicide application on A and B plots could potentially influence adjacent C plots (no herbicide). In order to determine independence among plots, we used a Generalized Linear Model (GLM, binomial distribution, LOGIT link function) for the set of 90 plots to explore how the proportion of re-sprouted shoots in a C plot may be influenced by: 1) the number of adjacent A plots; 2) number of adjacent B plots; 3) number of adjacent C plots; and 4) 2-level and 3-level interactions between independent variables.

Table 2. Mean of stems per plot. Treatment A (cut stems, 5% foliar application followed by second foliar application of 3%); treatment B (cut stems, 5% foliar application followed by second foliar application of 1.5%); treatment C – control. t0 - before *A. donax* treatment application; t1 - before the first foliar application; t2 - before the second foliar application ; t3 - one year after cutting. Mean (stems/plot) separation using GLM. The mean difference is significant at α=0.05 level. Values in parentheses are standard deviation.

Treatment	t0	t1	t2	t3
A	28.25 (1.95)	8.00 (0.91)	5.8 (1.10)	0.10 (0.10)
B	27.27 (2.15)	8.40 (1.07)	5.4 (0.77)	0.67 (0.32)
C	27.23 (2.35)	7.10 (0.77)	17.77 (1.64)	15.4 (1.32)
Mean	27.67 (1.23)	7.83 (0.53)	9.66 (0.93)	5.39 (0.88)

Table 3. Decision Matrix with data of effectiveness, herbicide and time spent cutting stems and time for foliar application per treatment.

Treatment	Effectiveness (stem/m^2)	Herbicide (ml/30 plots)	Cutting time (min/30 plots)	Spraying time (min/30 plots)	Rank
A	0.10	166	162	62	0.497
B	0.67	149	155	63	0.516
C	15.40	0	155	0	0.5
Total	-	315	472	125	-

We calculated the proportion of re-sprouted shoots as ratio of the number of shoots after last treatment to the number of stems before the manual control. A second GLM was used to select best control treatment (as measured by the number of re-sprouted shoots after 1 year of control application). Three factors were included in the model: time, treatment and the interaction between the two. Final numbers of re-sprouted shoots are the dependent variable.

Costs: The Simple Additive Weighting (SAW) method (Mysiak *et al*. 2002) was used to help select the best and most cost effective treatments. Two qualitative and two quantitative decision criteria were selected. The qualitative criteria helped to identify the most effective treatment according to herbicide quantity applied. The quantitative criteria helped to identify the most cost effective treatment i.e. time needed to cut stems and apply herbicide. Transportation of materials and personnel was not considered in the SAW analysis because it was a fixed cost regardless of control method.

CONSEQUENCES

Effectiveness: A total of 2,490 *A.donax* plants (t0) were removed from the 90 plots, in 472 mins (Table 3). Six weeks later (t1) 28% of stems had re-sprouted to about 1 m in height (Table 2). The first foliar application was applied immediately after t1 (treatments A and B). In October 2009 the new re-sprouted shoots were counted.

The herbicide application on A and B plots did not influence C plots (without herbicide). The proportion of re-sprouted shoots was not significantly different (Shapiro-Wilk test; $W > 0.86$). Treatment did not seem to effect neighboring plots ($p = 0.28$).

A. donax was cut on treatment C to understand the response of the plant through the year. The numbers of shoots re-sprouted quickly increasing a density (stem/m^2) up to 56% from original values.

After the first foliar application (t2) there are significant differences ($p<0.0001$) between the two treatment models (traditional and integrated). However there are no significant differences between integrated models from t0 to t3 (A and B, Fig. 2). From t1 to t3, the integrated models reduced the number of stems by between 92% (B) to 99% (A). The number of re-sprouted stems using the traditional method increased by 207%; the lowest density achieved was 0.1 stem/m^2. According to Lawson *et al*. (2005), the density after 1 year of treatment with herbicide solution of 6% was 0.04 stem/m^2. This demonstrates that the integrated treatment is the best method for *A. donax* control, though it is unclear which combination of herbicide treatments produced the best results.

Costs: An average density of 27.6 stems per plot was cut in 5.24 min. In this test 315 ml of herbicide was used in 125 minutes (Table 3). The total cost of the intervention was €213 (herbicide, staff and transportation). According to the model the best control method is treatment B with highest rank (0.516), which reflects the higher efficiency, reduced amount of herbicide and less labour. Treatment C has higher rank than A owing to the null values of herbicide and time of spray. However, it is the least efficient treatment. Total cost of treatment B was €0.66/m^2 versus €0.68/m^2 for A. To control *A. donax* in the islet using treatment B and a team of six people is estimated at €8,000.72/ha in the first year, of which €1,325 is for boat transportation. Technical support and monitoring costs are not included.

Foliar herbicide application may increase the risk of non-target species contamination (ISSG 2011). However, the amounts of herbicide used in these trials did not cause any mortality to endemic species around the test site. In fact, a high number of trees re-sprouted and produced seed after *A. donax* removal. We however detected seven new invasive plants where *A. donax* was removed: *Achyranhtes sicula*, African tamarisk *Tamarix africana*, American pokeweed *Phytolaca americana*, Australian cheesewood *Pittosporum undulatum*, maguey *Agave americana*, lantana *Lantana camara*, metrosideros *Metrosideros tomentosa* and red apple aptenia *Aptenia cordifolia*. Control efforts have subsequently been adopted (hand removal) for the most invasive: *A. sicula*, *L. camara* and *P. americana*.

Discussion: On the Azores, *A. donax* eradication has been attempted for decades, however it continues to invade coastal areas (Silva *et al*. 2008). Because 5 months after the first foliar application of 5% herbicide new shoots had re-sprouted, we recommend that *A. donax* control would most effective by using two foliar applications, without cutting stems in late September (despite higher cost). This results in a rapid increase in native vegetation cover, thus improving both floristic quality and access to nesting sites for Cory's shearwaters. Since 2010 an area of 1.34 ha was being managed with the best treatment method identified by these trials. Although *A. donax* control was fairly effective, some shoots re-sprouted and it is therefore necessary to continue the control effort. The time needed for these operations has not been yet determined. However, this subsequent follow-up management is far less expensive than first year (more intensive) control.

In 2006, 34 nests of Cory's shearwater were found inside the intervention area (Rodrigues *et al*. 2009). After control efforts, 319 nests were detected inside the same area. Of these, 101 had eggs or chicks (SPEA 2010). The effectiveness of this innovative technique has encouraged us to plan a wider habitat restoration program by eradication *A. donax*.

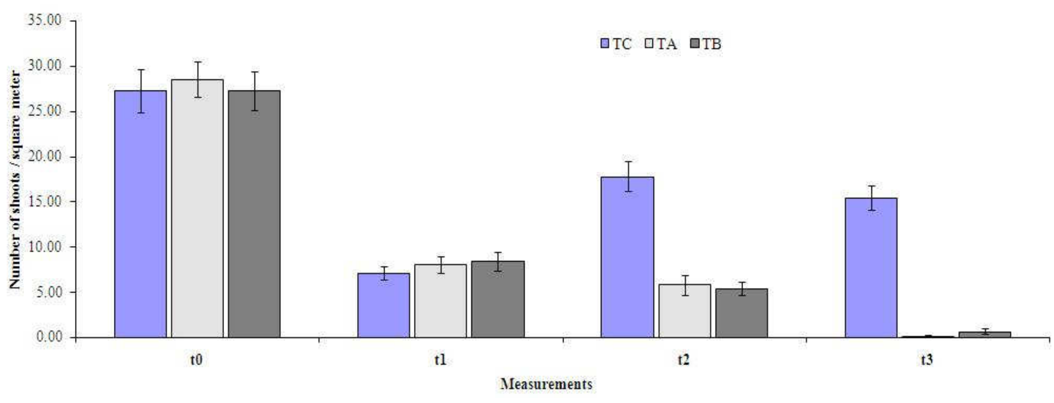

Figure 2. Number of *A. donax* shoots re-sprouting after control efforts. Mean of stems per plot. TA – treatment A (5% foliar application followed by second foliar application of 3%); TB – treatment B (5% foliar application followed by second foliar application of 1.5%); TC – treatment C (cut stems). t0 - before the *A. donax* control; t1 –5 weeks after cutting ; t2 – 5 months after the first foliar application of herbicide; t3 – 5 months after the second foliar application of herbicide.

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