An experimental test of a visual-based push-pull strategy for control of wood boring phytosanitary pests.

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Abstract

International phytosanitary standards require mandatory fumigation for key wood boring beetle pests prior to export. Pressure to reduce the use of toxic fumigants has created a need for alternative control techniques. A visual based push-pull strategy that exploits a differential attraction to yellow and ultra violet (UV) lights was tested for its efficacy at controlling Cerambycidae.

The relative attraction of four 'push' lighting treatments: two yellow (high and low pressure Sodium), one white (metal halide) and a control (no light), to beetles was assessed. Highly attractive UV 'pull' traps were deployed in tandem and beetle catch relative to a paired control traps was used as a measure of the UV traps effectiveness at trapping residual beetles attracted by 'push' lights.

Control 'push' lights had the highest average catch of *A. ferus*, whereas white light was least attractive (this was counter intuitive to expectations, and potential mechanisms are discussed). The white 'push' light was most attractive to *P. reticularis.* Trap catch beneath the two yellow lights was more similar to the control (no light) treatment than the white light for both species. Ultraviolet 'pull' traps were highly effective at trapping residual beetles attracted by yellow 'push' light treatments, were partially effective beneath control 'push' lights, but were not effective beneath white lights. Results suggest a push-pull strategy that combines yellow site lighting with UV kill traps could provide site specific control of wood borers. Future research should attempt large-scale trials subject to competing alternative stimuli at a wood processing site.

Key words: stimulo-deterrent diversionary strategy, Cerambycidae, quarantine standard, mass-trapping, light trapping, alternatives to fumigants.

Introduction

International export phytosanitary standards regulate the trade of logs, timber, and wood packaging materials as they are known pathways for the introduction of wood borers and bark beetles (Brockerhoff et al., 2006a; Haack, 2006). Standards developed following the International Plant Protection Convention, 1997, require approved phytosanitary measures to be applied when exporting logs, timber and raw wood packaging (IPPC, 2002; FPIER, 1989). Due to its effectiveness, methyl bromide is the principle fumigant currently accepted by most countries for wood products (Barak et al., 2005; Ray, 1972), however it is also used by many other industries (Thomas, 1996). The use of methyl bromide, a highly toxic ozone depleting gas, is regulated by the Vienna Convention and the Montreal Protocol on substances that deplete the ozone layer (Anon, 1998). Major initiatives are under way to develop appropriate phytosanitary treatments and viable alternatives for methyl bromide (IFQRG, 2007; IPCC, 2007; IPPC, 200?). Several alternative fumigants have been trialled including sulfuryl fluoride (Barak et al., 2006) and in-hold phosphine fumigation during transit (Glassey et al., 2007), with varying degrees of success. Alternative fumigants will satisfy the requirements of the Vienna Convention, however fumigants by their nature are highly toxic and public health concerns may limit their future use. As such, research into non-toxic pest management techniques is required.

The importance of light as an attractor of some nocturnal insects is universally known. Indeed light traps were used as early as the 1st century BC by early Roman bee keepers to control pyralid moth pests (Steiner, 1991). Recently light traps have been used extensively for terrestrial insect population monitoring (Nair et al., 2004; Steinbauer, 2003; Takahashi & Higuchi, 2002), although its exploitation as a pest control tool has been more limited. The most notable uses of light for control are indoor pests, especially the house fly (Chu et al., 2006; Roberts et al., 1992; Syms & Goodman, 1987), and some stored product pests (Nualvatna et al., 2003). Preliminary attempts at the control outdoor pests have been reported (Jess & Bingham, 2004; Rodriguez Jimenez et al., 2002; Aragon-Garcia et al., 2008; Walliner et al., 1995), however they appear to have achieved comparatively less success than other behavioural modifying stimuli, such as semiochemicals (Foster & Harris, 1997).

Light can be used in sophisticated ways to control unwanted pests. A proposal in the 1960s that utilised highly attractive decoy light traps to pull insects away from sensitive areas is perhaps one of the earliest references to the concept of a push-pull strategy (Barrett et al., 1974; Killough, 1961). Push-pull strategies refer to the simple use of attractive and deterrent stimuli that in combination modify the behaviour of pest species (for a recent review see Cook et al. (2007)). Deterrents are used to push unwanted insects away from a resource, e.g., crops, whilst highly attractive pull stimuli are used in tandem to lure potential pests away from desired resources. The concept relies on the notion that each tool used independently is only partially effective, but synergistically they can have a significant impact on pest populations (Cook et al., 2007). Most push-pull strategies implemented to date utilise semiochemicals; host volatiles or pheromones (e.g., mating or aggregation) are commonly used attractants, whereas anti-feedants, non-host volatiles and alarm pheromones are used as deterrents (Cook et al., 2007). Given the practicalities of altering the colour or appearance of crops or livestock, it is not surprising that visual cues are infrequently used in push-pull strategies (Cook et al., 2007; Foster & Harris, 1997). Although semio-chemicals are often the primary mode of operation in push-pull strategies, visual cues such as the colour of mass-trapping systems have proved important (Schmera et al., 2004; Gibson & Torr, 1999; Wu et al., 2007; Laubertie et al., 2006; Cornelius et al., 1999).

Arhopalus ferus (Mulsant) was first recorded in New Zealand in the 1960s and attacks dead trees, principally *Pinus radiata* (Hosking & Bain, 1977). Although it does not oviposit or attack sawn timber, *A. ferus* has a propensity to use crevices in timber pallets as daytime refugia (Hosking & Bain, 1977). It is this behaviour that necessitates fumigation of timber prior to export from New Zealand. Previous research has shown *A. ferus* to be strongly attracted to bright lights, particularly ultra-violet (here after referred to as UV), but only weakly attracted to yellow light (Pawson et al., Submitted). This study was designed to experimentally test whether the relative attraction to different coloured lights could be exploited as a push – pull strategy to control infestations of *A. ferus*. We hypothesise that the two yellow light treatments will attract fewer beetles than the white light. During the course of the study large numbers of another native cerambycid beetle (*Prionoplus reticularis* White) were attracted to the traps. This species is also a quarantine pest and data are also presented for this species.

Methods

The experiment was conducted in Pigeon Valley forest, which is part of the larger Moutere Plantation in Nelson, New Zealand (latitude 41° 22' S, longitude 173° 1' E). The study region has an average temperature of 12.5 °C, a total annual rainfall of 1,100 mm (Niwa, Cliflo, http://cliflo.niwa.co.nz) and an altitudinal range of 180-260 m.a.s.l. The plantation consists almost entirely of *Pinus radiata* with a few small areas of other species, e.g., *Eucalyptus* spp. Trials were situated in areas clearfelled 12 months prior, as the known life-cycle of *A. ferus* suggested that these stands would constitute a significant source population (Hosking & Bain, 1977). The experiment was run over an eight night period from 7 – 14 February 2008, a known period of high flight activity (Pawson and Brockerhoff, Unpublished data).

In this study the push-pull design assessed four 'push' treatments that included three types of light and a no-light control. It should be noted that most lights have some degree of attraction to *Arhopalus* (Pawson et al., Submitted) and as such by 'push' we refer to the search for the least attractive stimuli. All 'push' lights were enclosed in Gough GL500 (Gough Technology, Christchurch, New Zealand) weather proof lighting enclosures. The four push light treatments were: low pressure Sodium (SOX), Osram SOX 35W LPS (4600 luminous flux, OSRAM, Germany), high pressure Sodium (SON) Osram NAV T 50W E27 SUPER 4 Y HPS (4,400 luminous flux, OSRAM, Germany), metal halide (MH) elliptical coated Power Star HQI-E Light (4900 luminous flux, OSRAM, Germany) and control (no light). Low pressure sodium lights are monochromatic and emit light at two frequencies (589.0 and 589.6 nm) in the yellow spectrum, a colour known to be least attractive to *A. ferus* (Pawson et al., Submitted). High pressure sodium and metal halide lights were selected as they are two commonly utilised site lights at large industrial sites. High pressure sodium lights have a predominantly yellow spectral output, whereas metal halide lights are white. Power ratings for each light type were chosen to minimise differences in luminous flux (light intensity) between treatments, as intensity is known to affect catch rates (Hosking, 2005).

One 'push' light treatment was applied to each of the four corners of a square (Fig. 1a). Additional highly attractive UV 'pull' traps (and their paired no light control trap) were also installed at each of these corners (Fig. 1a). At the centre of each replicate an electric generator provided power by means of a 35 m extension lead to each treatment. The 'push' light treatments were fixed by a metal bracket 4 m above the ground on a square wooden post (100 x 100 mm) (Fig. 1b). Beetles were sampled from the UV 'pull' traps and their paired control. Pull traps consisted of square green 30 litre plastic containers (600 x 600 mm square) placed 3 m either side of the base of the central 4 m 'push' treatment pole (Fig. 1b). Wet traps were used as they are known to be more effective at trapping some Coleoptera (Miller & Duerr, 2008), and buckets were filled with 30 mm of water (laced with normal household detergent). Bucket traps were fixed to the base of a 2 m post (100 x 100 mm). A 1.5 m sheet of corrugated roofing iron was attached to the post above the bucket. A 0.9 m vertically orientated UV light (NEC 40WBL, NEC, Japan) was attached to the post just above the bucket trap using an IP65 weather proof housing (Fig. 1b). The IP 65 housing was covered in black polythene and a narrow central 30 mm strip of highly attractive UV light was produced radiating towards the central 4 m post that supported the 'push' light treatment. Shielding was deemed necessary to eliminate long distance UV attraction; as such, insect catch in the UV and control 'pull' traps should reflect the relative attraction of the 'push' lights.

Five replicates of the push-pull square design were established on old logging skids. Skid sites were selected as they provided a flat area with suitable access for trial maintenance and minimised the danger of accidental fire from generators. To account for potential site effects, e.g., topographical influences, 'push' light treatments were rotated every second night and the UV and control 'pull' traps were alternated in between the 'push' light changes. All electric generators were started prior to dusk (~ 21:00) and were left running for at least two hours. At 23:00 hours the first generator was turned off and beetles in each 'pull' trap were counted. The time was noted when each of the other four generators was turned off and beetle counts were standardised for further analysis as catch per hour of generator time after the start point at 21:00 hours. In addition to counting beetles in 'pull' traps a note was taken of the number of beetles present on each of the standing posts.

All analyses were undertaken using SAS (SAS-Institute-Inc, 2000). For each insect species, light type (push and pull), and replicate, insect abundance data were summed over the eight night collection period and averaged to an hourly collection rate. Using this dataset, mixed effects models which included random terms to account for the split plot design of the experiment were used to examine the main and interactive effects of push and pull lights on insect abundance, by species. To ensure that the correct denominator degrees of freedom were used for each term the Satterthwaite's approximation was specified in the model statement. As residuals from these models were not normally distributed for *P. reticulatus*, abundance data for this species was transformed to achieve normality using the following scaled power transformation (Cook & Weisberg, 1999) $Y_t = [(Y+1)^{-0.4} - 1]/-0.4$ where Y and Y_t are the untransformed and transformed data, respectively. Multiple comparisons were undertaken by examining the significance of least square differences using a t-test.

Results

A total of 671 *A. ferus* and 1,661 *P. reticularis* were caught in UV and control 'pull traps over the eight night trapping period.

'Push' lights:

All results presented in this section refer to the combined average catch of the UV and control 'pull' traps associated with each 'push' light treatment. *Arhopalus ferus* and *P. reticularis* catch differed significantly between the four (MH, SON, SOX and control) 'push' light treatments (Table 1). Control 'push' treatments (no light) had the highest average catch of *A. ferus* (1.22 individuals per trap hour). In contrast metal halide lights attracted the least *A. ferus*, but were most attractive to *P. reticularis* (2.94 individuals per trap hour). Average trap catch of *A. ferus* were 37.9, 63.6 and 68.7 % of the control 'push' light catch for MH, SON and SOX respectively (Fig. 2). Average trap catch of *P. reticularis* were 237.0, 129.9 and 117.4 % of the control light catch for MH, SON and SOX lights respectively (Fig. 2). Catch beneath the two yellow lights (SON and SOX) was more similar to the control (no light) than the MH 'push' light treatment for both species assessed. Visual inspections when the generators were switched off showed *P. reticularis* to be strongly attracted to posts that supported the MH lights compared to other treatments (Table 2.). In contrast *A. ferus* abundance was similar on posts beneath control, SON and SOX lights but much lower under MH lights (Table 2). Anecdotal observations during the course of the study recorded much greater insect flight activity surrounding MH lights, especially Lepidoptera and other non-target Coleoptera.

'Pull' lights

Results presented in this section compare the average trap catch in UV and control 'pull' traps beneath the four 'push' light treatments.

Average catch in UV 'pull' traps pooled across all 'push' treatments was 747 % and 234 % more than paired control traps for *P. reticularis* and *A. ferus* respectively. The UV-control-trap comparison was the strongest effect tested (Table 1), and was significantly different in all species and light treatment combinations, except for the catch of *A. ferus* at MH lights (P=0.339).

Catches of *P. reticularis* in the UV 'pull' traps beneath yellow 'push' lights were the same as the no-light (control) 'push' treatment (P = 0.493 and P = 0.648, SOX and SON respectively). In contrast UV traps beneath white metal-halide lights trapped significantly more *P. reticularis* than the control 'push' light treatments (P<0.036) (Fig. 3a). Furthermore UV 'pull' traps were highly effective at trapping residual *P. reticularis* attracted to the two yellow lights; as shown by the low trap catch in control 'pull' traps beneath these SOX and SON treatments (Fig. 3a, Table 3). Ultra violet 'pull' traps were less effective at trapping residual *P .reticularis* beneath metal-halide lights. *Prionoplus reticularis* caught in control 'pull' traps beneath MH lights was significantly greater than all other light treatments (control, P <0.001; SON, P=0.003; and SOX, P=0.001 respectively).

In contrast to our expectations the UV 'pull' trap beneath the MH lights caught fewer *A. ferus* than UV traps beneath the other 'push' light treatments (control, P < 0.001; SON, P=0.004; and SOX, P=0.013 respectively) (Fig. 3b). There was no difference in the catch of *A. ferus* in UV 'pull' traps beneath SOX, SON and control 'push' light treatments. Catch of *A. ferus* in control 'pull' traps was significantly less than their paired UV 'pull' trap beneath SON (P <0.001) and SOX (P = 0.005) 'push' light treatments, but was not significantly different beneath control (P = 0.010) or MH lights (P = 0.339) 'push' light treatments (Fig. 3b).

Discussion

Our visual based push-pull control strategy can be deemed effective if the two stimuli in combination satisfy the following criteria: 1) one 'push' light treatment attracts fewer beetles compared to other lights, or is no different from the no-light control; and 2) beetle catch in the control 'pull' trap beneath the least attractive 'push' light treatment is minimal relative to its adjacent UV 'pull' trap. Low trap captures in control 'pull' traps and high catches in UV 'pull' traps indicate that the UV light traps are effective at trapping residual individuals attracted to the site, either from 'push' lights or alternative stimuli present at the site, e.g., host volatiles such as α – pinene and ethanol.

The results of our in forest field trials suggest that the push-pull concept, of utilising the relative attraction of different light spectra, could significantly reduce wood borer beetle populations from illuminated areas during peak flight periods. It is encouraging to note that the cerambycid catches in UV 'pull' trap catches beneath the SOX and SON (yellow lights) were no different from those caught in UV traps beneath the no-light control. This shows that SOX and SON lights are poor attractants of *A. ferus* and *P. reticularis*. However, most importantly the trap catch in control 'pull' traps had up to 96% fewer beetles than the adjacent UV traps beneath SON lights. This indicates that the UV kill traps are highly effective at removing residual *A. ferus* and *P. reticularis* attracted to lights on 4 m high posts, particularly beneath yellow (SOX and SON) lights. The UV traps used in this trial were only 40 W and most of their energy was shielded (see methods). As such, large commercial 320W unshielded UV pane trapping systems (trialled elsewhere (Hosking, 2005)) may provide greater control of beetles at larger spatial scales.

White light is known to be more attractive to *A. ferus* than yellow light (Pawson et al., Submitted). As such, the low trap catch of *A. ferus* beneath white MH lights is counter intuitive to our initial hypotheses. The underlying cause of this observation remains unknown, however observations recorded throughout the trial did show greater insect activity associated with white MH lights (Table 2). For example one instantaneous count recorded 88 *P. reticularis* on the 4 m high lamp post and the ground within 1 m of the post supporting the MH light! This strong response to metal-halide light by *P. reticularis* may have been a significant factor in reducing the trap catch of *A. ferus* beneath metal-halide lights. *Prionoplus reticularis* are a large stout cerambycid beetle (up to 50 mm (Hosking, 1978)) whereas *A. ferus* is by comparison smaller and more slender (12-30 mm in size (Brockerhoff & Hosking, 2001)). The physical competition of large numbers of *P. reticularis* may have contributed to a reduction in *A. ferus* attracted to MH lights. Alternatively semiochemicals released by an aggregation of *P. reticularis* may serve as a repellent to *A. ferus* that compete for similar host resources (dead *Pinus radiata*). Both intra-specific and inter-specific examples are known where anti-aggregation semiochemicals interrupt the population dynamics of bark beetles (Ryker & Yandell, 1983; Fettig et al., 2005), and their potential as a component of push-pull strategies has been discussed (Lindgren & Borden, 1993). However, further experimental testing is required to evaluate these and other potential explanations for the low catch rates of *A. ferus* at MH lights in this experiment.

The research reported here was conducted at peak flight activity in a forest situation. The question arises, are push-pull strategies sufficient to control wood boring insects at wood processing mills when alternative stimuli are present and at different times of the year? Nationwide trapping surveys have shown that semiochemicals such as α-pinene and ethanol (and in the case of *A. ferus* burnt wood odours (Suckling et al., 2001)) are highly attractive to wood borers (Brockerhoff et al., 2006b). At sawmills wood is often burnt to generate heat, and these kilns and furnaces produce large quantities of highly attractive semiochemicals. This may account for the increased density of some wood borers present at saw mills compared to forest sites (Suckling et al., 2001). The relative attraction of light versus semiochemicals is unknown, but will be critical to the overall success of a visual based push-pull strategy.
Previous work has shown that small UV light pane traps caught over an order of magnitude more *A. ferus* than α-pinene and ethanol baited Lindgren funnel traps (Pawson et al., Submitted). Despite this disparity, it must be acknowledged that Lindgren funnel traps are less effective than pane traps at catching large cerambycids (McIntosh et al., 2001; Groot & Nott, 2001). Although semiochemical release rates are known to influence trap catch rates (Miller & Borden, 2000) a mass-trapping approach that relies on chemical baits (as proposed by McIntosh et al. (2001)) is unlikely to achieve control in situations were competing semiochemical sources are present. Given the practicalities of eliminating α-pinene releases from wood drying kilns, light management in conjunction with UV mass trapping may prove a more effective trapping option for reducing cerambycid beetles at wood processing sites. The next step is to undertake an operational trial of a push-pull strategy at a wood processing site across the entire flight season and assess the level of control achieved.

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Tables

Table 1. Main and interaction effects of push-pull strategies on insect abundance. Values presented are F- values followed by *P* values in brackets

Species	Push (site lights)	Pull (UV light traps)	Interaction
Arhopalus ferus	7.3 (0.0009)	32.8 (<0.0001)	2.1 (0.12)
Prionoplus reticularis	8.8 (0.0023)	231.0 (<0.0001)	2.0 (0.15)

Table 2. Average abundance (SE in brackets) of beetles observed sitting on central lamp post or within 1 metre of the post when generator was turned off.

Light Type	*A. ferus*	*P. reticularis*
Control	1.78 (0.55)	0.15 (0.08)
MH	0.80 (0.17)	5.40 (1.12)
SON	2.05 (0.73)	0.85 (0.19)
SOX	1.45 (0.41)	0.48 (0.13)

Table 3. Percent reduction in the average catch per hour of *A. ferus* and *P. reticularis* in control traps relative to paired UV traps beneath different 'pull' light treatments.

Light Type	*A. ferus*	*P. reticularis*
Control	43	98
Metal Halide (MH)	39	74
High Pressure Sodium (SON)	81	90
Low Pressure Sodium (SOX)	59	96

Figure 1. A) Spatial design of individual replicate showing four push treatments, and B) individual treatment, showing location of push and pull traps

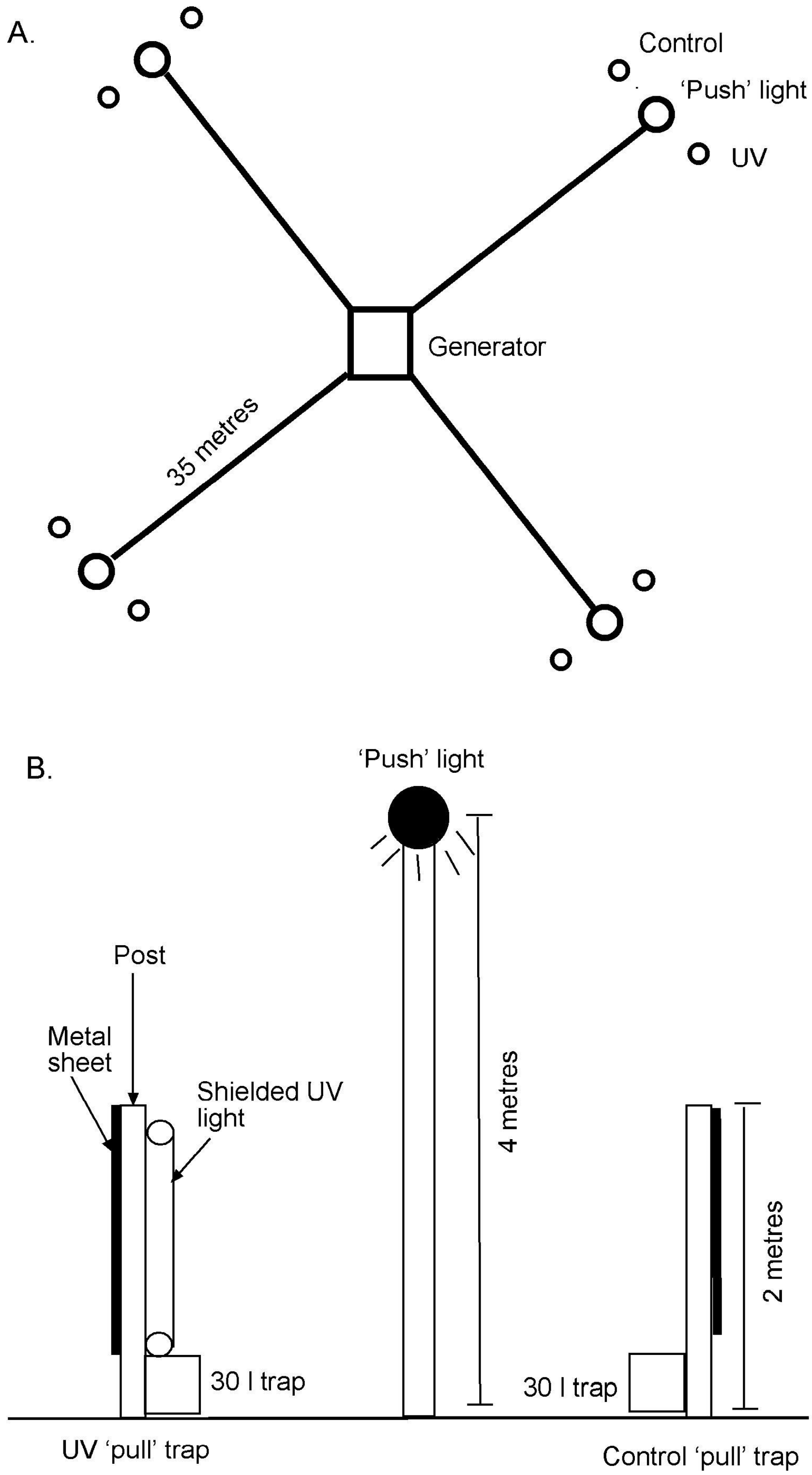

Figure 2. Average catch per hour of *A. ferus* and *P. reticularis* at each 'push' light treatment. Note: species have been offset for clarity.

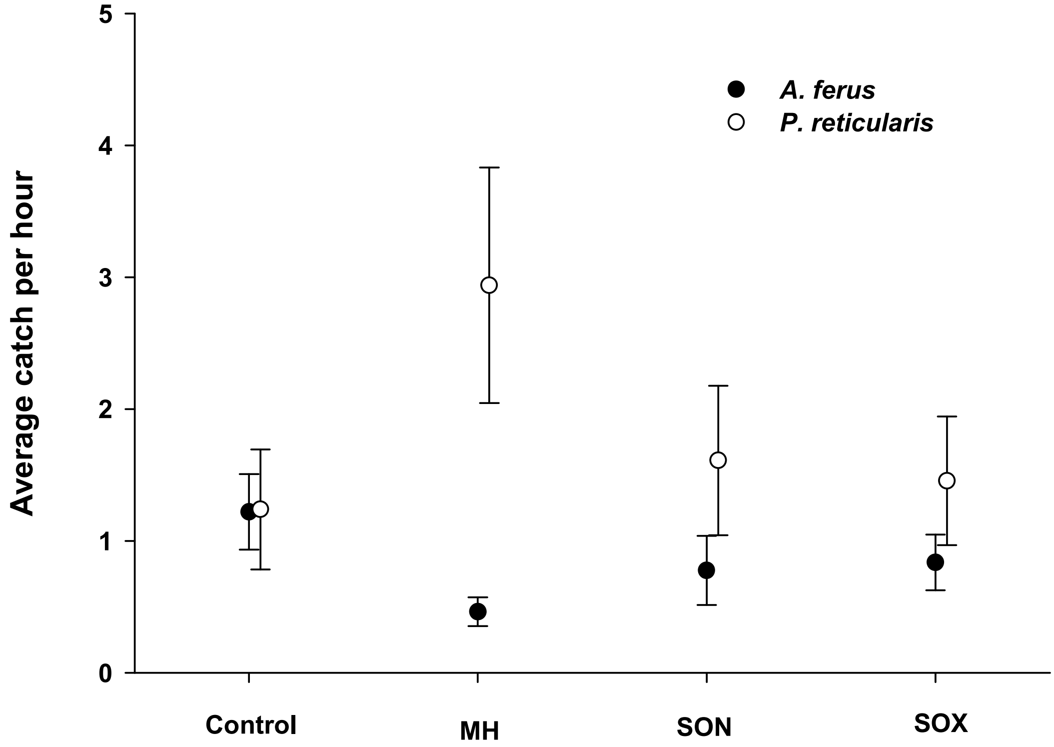

Figure 3. Average catch per hour in UV and adjacent control 'pull' traps beneath the four 'push' light treatments of: A) *P. reticularis* and B) *A. ferus*.