Ecological impacts of *Carijoa riisei* on black coral habitat

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In 2001, the alien octocoral, *Carijoa riisei*, was discovered overgrowing commercial black coral species, *Antipathes dichotoma* and *A. grandis*, in the Au'au Channel between the islands of Maui and Lanai (Grigg 2003). The unknown, long term ecological impact of this biological invasion raises new questions regarding the sustainable yield of the commercial black coral harvest in the Au'au Channel (Grigg 2004). In 2001, 2003, and 2004, deep-water surveys using the Hawaii Undersea Research Laboratory (HURL) *Pisces IV* manned submersible and *RCV-150* remotely operated vehicle (ROV) revealed that the overgrowth was widespread in the Au'au Channel with a maximum impact between 70-110 m where >50% of black corals had *C. riisei* overgrowth (Kahng and Grigg 2005). To determine whether the ecological impact of *C. riisei* is worsening with time, a new survey was conducted in October, 2006 in the Au'au Channel, Hawaii. An effort was made to replicate areas previously surveyed in the Keyhole Pinnacle area to enable a comparative analysis across time.

During October 21-26, 2006, a research cruise was conducted in the Au'au Channel using the HURL *Pisces IV* manned submersible and *RCV-150* ROV. A total of two submersible dives and three ROV deployments were conducted (Fig. 1). The Keyhole Pinnacle in the northern end of the Au'au Channel was surveyed (P4-173, RCV-347) in an attempt to replicate previous survey tracts. A second pinnacle 1.4 km to the northeast, the "East Pinnacle," was also surveyed (P4-174) to investigate the black coral population on a nearby site with similar topography. The submersible dives were also used to explore the lower depth limits associated with both *C. riisei* and commercial black coral species (*A. dichotoma* and *A. grandis*). Two ROV deployments (RCV-348, RCV-349) were conducted in the southern end of the channel to determine the extent to which *C. riisei* is impacting the southern black coral populations.

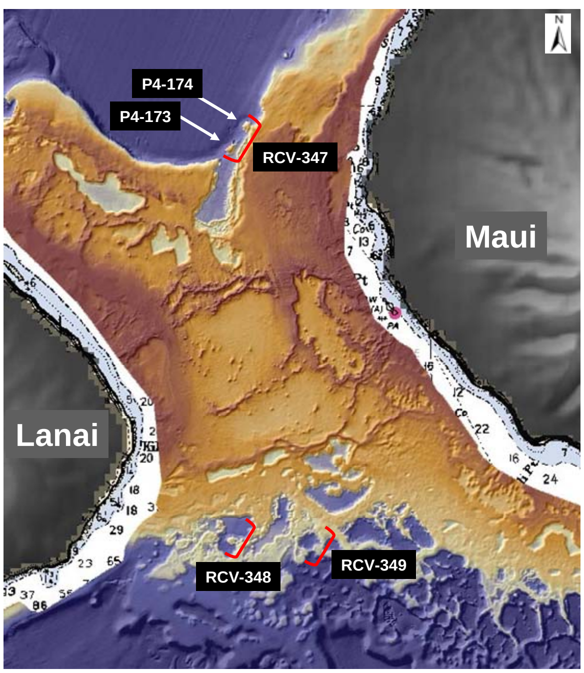


Figure 1. Location of HURL submersible dives and ROV deployments during October, 2006.

Time Series Analysis – Keyhole Pinnacle

Analysis of the 2006 video data in the Keyhole Pinnacle (P4-173, RCV-347) suggests that the impact of the alien octocoral, *C. riisei*, on black corals has not worsened in the past five years (Fig. 2). In fact, the 2006 results show less impact than each of the previous years. It is possible that the situation at the Keyhole Pinnacle has stabilized or even improved. However, it is important to note that despite efforts to be consistent the survey transects in 2001, 2003, 2004, and 2006 were not identical. On the deep reef where large physical disturbances are rare, black corals and *C. riisei* have long life spans and black coral skeletons take time to erode (Grigg 1965; Grigg 1976; Kahng 2006). Therefore, the differences between years may reflect differences in the samples (Fig. 3).

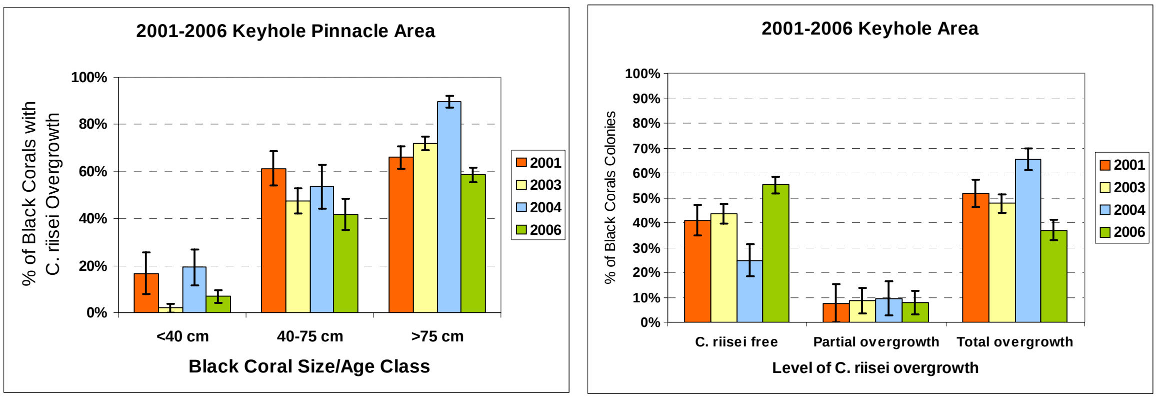


Figure 2. Time series analysis of percentage of black coral colonies with *Carijoa riisei* overgrowth by size class (*left*) and by level of overgrowth (*right*).

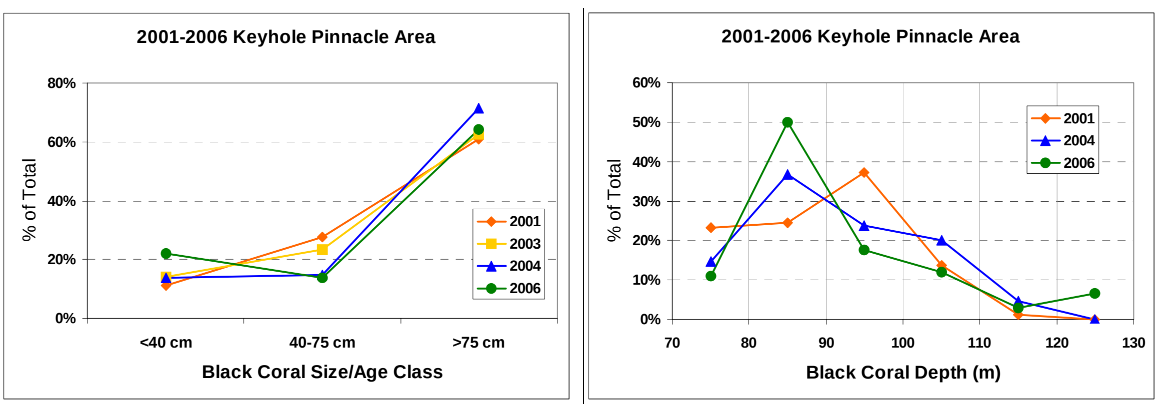


Figure 3. Differences in the Keyhole Pinnacle survey samples by year: size frequency distribution (*left*) and depth distribution (*right*). Sample sizes were as follows: 2001 (n=159), 2003 (n=369), 2004 (n=189), 2006 (n=395). Depth data was not available in 2003 due to CTD malfunction.

Evidence suggests that the ecological impact on the main Keyhole Pinnacle may be worse than in neighboring areas. A comparison of the main Keyhole Pinnacle (P4-173) with the neighboring East Pinnacle (P4-174) illustrates that the percentage of black coral colonies overgrown by *C. riisei* can vary considerably across small spatial scales (Fig. 4). The patchiness of black coral overgrowth by *C. riisei* was also evident within each survey transect. The main Keyhole Pinnacle and the East Pinnacle share similar topography and fauna and are separated by less than two km. However, the level of ecological impact of *C. riisei* is visibly less on the East Pinnacle. Black corals (*Antipathes* spp.) on the East Pinnacle appear less "bushy" which is consistent with the hypothesis that current speed decreases to the east. It is possible that greater average current speeds facilitate more rapid proliferation of *C. riisei* both on the substrata and on black coral colonies. Since *C. riisei* grows roughly 10 times faster than *A. dichotoma* and both are passive suspension feeders, a stronger current regime would disproportionately favor *C. riisei* (Kahng 2006).

In general, the higher incidence of overgrowth on larger colonies in 2006 was consistent with previous surveys (Fig. 2). A large black coral colony has an increased exposure to *C. riisei* due to its size, longevity, and, in some cases, colonization by other fouling organisms (Kahng and Grigg 2005). Small black colonies are rarely fouled with *C. riisei* or other fouling organisms. In addition to *Antipathes* spp., *Myriopathes* spp. (e.g., feathery black coral) were observed with *C. riisei* overgrowth. *C. riisei* was also observed colonizing the undersides of zooxanthellate, scleractinian corals (*Leptoseris* spp.) and overtopping them. Wire corals (*Stichopathes* spp. and *Schizopathes* spp.) did not appear to be subject to *C. riisei* overgrowth.

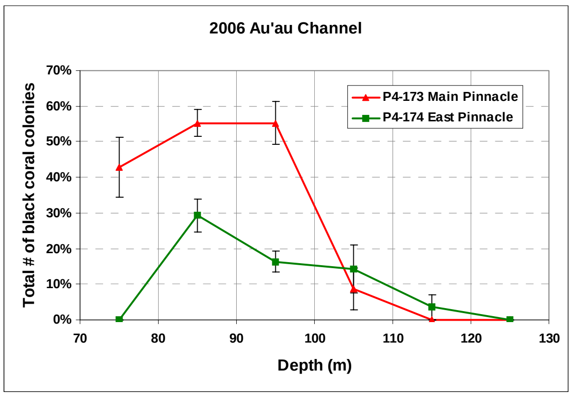
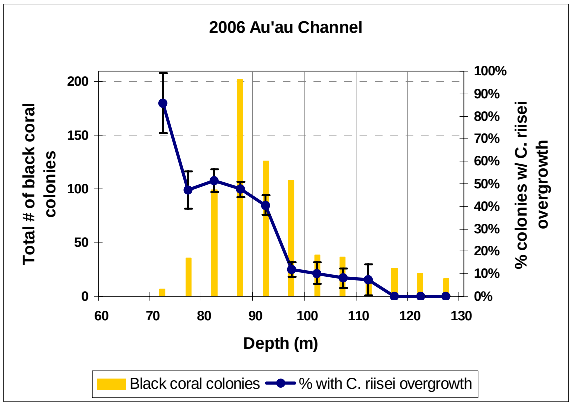


Figure 4. Depth distribution of black coral overgrowth by *C. riisei* for two survey transects: the main Keyhole Pinnacle and the East Pinnacle (1.4 km apart). Sample sizes were as follows: P4-173 (n=303) and P4-174 (n=331).

Patterns of Distribution in the Au’au Channel

An investigation of the lower depth limit of black coral in the Au’au Channel revealed that black corals visibly decreased in abundance and average size below 100 m. Between 110-130 m, *Antipathes* spp. were rare and most black corals observed were small *Myriopathes* spp. In this depth range, other sessile benthic fauna also decreased in abundance. Exposed hard substrata were often barren below 120 m which coincides with the bottom of the seasonal thermocline in the Au’au Chanel (Kahng 2006). Lower temperature below the seasonal thermocline may slow metabolic processes below the threshold required for net annual growth or viable larval settlement. Below 130 m, no black corals were observed.

In the Au’au Channel, a vast majority of the overgrowth of black corals by *C. riisei* occurs between 70-110 m (Fig. 5). Below 100 m in the Au’au Channel, the incidence of *C. riisei* on the substrata decreases sharply with depth (Kahng and Kelley in review). The deepest record of *C. riisei* on the substrata was observed at 120 m. The incidence of *C. riisei* overgrowth of black corals declined significantly near its observed lower depth limit (Fig. 5). In the Au’au Channel, a combination of cooler temperatures, fewer black corals, and smaller black corals correlate with increasing depth below 100 m.



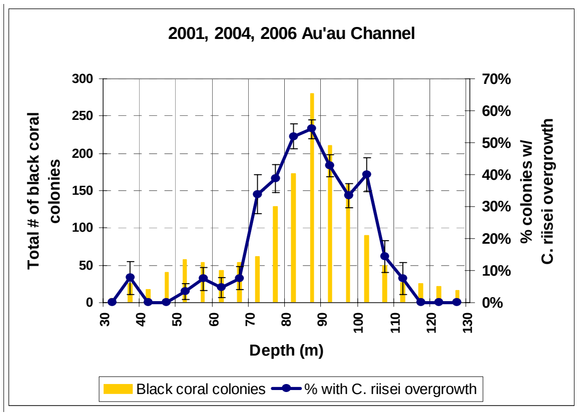


Figure 5. Depth distribution of black coral overgrowth by *C. riisei* in the Au'au Channel for all 2006 survey transects (*left*) and all data 2001, 2004, and 2006 (*right*)

Optical water clarity plays an important role in regulating the depths at which *C. riisei* can grow on exposed substrata and overgrow black corals and other coral fauna. In the Au'au Channel at depths above 70 m, the distribution of *C. riisei* appears to be regulated by direct exposure to light (Kahng 2006). Due to rough weather, optical casts could not be performed while the ship was inside the Au'au Channel. However, an optical cast was conducted nearby in the Kalohi Channel (N 21º 2.60 W 157º 11.04). The attenuation coefficient of downwelling light irradiance (PAR) was measured at K_d=0.0475. This optical water clarity is greater than analogous measurements at Penguin Banks where PAR K_d=0.052 (Agegian and Abbott 1985) and nearshore south Oahu where PAR K_d=0.056 (Kahng 2006) but less than open ocean values measured 10 km west of Oahu where PAR K_d=0.032 (Bienfang et al. 1984). Correlating this measurement to the depth distribution of *C. riisei* on exposed substrata in the Au'au Channel suggests that *C. riisei* is freed from light limitation at 4-5% surface irradiance. Additional measurements are required to confirm this optical threshold and determine the spatial variability due to terrigenous influence.

While black corals are abundant in the northern and central portions of the Au'au Channel (Grigg 1976, 2001, 2004), the 2006 surveys in the southern extreme of the Au'au Channel observed relatively few black coral colonies. However, the available data suggests that overgrowth of black corals by *C. riisei* is common on the relatively few black coral colonies that exist there. On RCV-348, four of six black coral colonies were observed with *C. riisei* overgrowth. No black corals were observed on RCV-349 where currents may be too weak. These results are consistent with two survey transects conducted in the southern Au'au Channel in 2004 (RCV-283, RCV-284).

Future black coral research

In order to determine the reproductive contribution of the deep water black coral population, several black coral samples were collected 85-110 m from large colonies. Contingent on future funding, the black coral samples will be analyzed using light microscopy histology to determine reproductive status, fecundity, and any correlation of these factors with depth & size. Large black coral colonies below harvesting depths are presumably an important source of larvae for seeding black coral populations in shallower depths subject to harvesting. However, deep water black coral colonies (i.e., below 70 m) have never before been analyzed for reproduction.

In order to identify the temperature threshold associated with the lower depth limits of *C. riisei* and commercial black coral species, 30 temperature loggers were deployed in two sets along depths gradient 60-150 m intersecting the black coral populations on the main Keyhole Pinnacle and the East Pinnacle in the northern end of the Au’au Channel. The temperature loggers will continuously record temperature every 30 min for 22 months. Contingent on future funding, the temperature loggers will be retrieved to analyze the temperature regime associated with the habitable depth range of both *C. riisei* and commercial black corals. This analysis will reveal the environmental limits associated with each species. Once known in absolute terms, these environmental limits can be used to assess the habitable range of these species throughout the Hawaiian Archipelago.

Given the results of the 2006 Au’au Channel survey, it is possible that the ecological impact of *C. riisei* on black corals, while severe, may have stabilized or possibly abated slightly. Serendipitously, the area where the phenomena was first discovered in 2001, the main Keyhole Pinnacle, may be center of the invasion’s intensity due to favorable environmental conditions there. It is recommend that the time series study be continued in 2008 (in two years) to monitor the ecological impact and verify whether the apparent change in trend identified in 2006 is a real long-term trend (e.g., has the biological invasion in the Au’au Channel already peaked?).

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