Appendix 8.

Distribution, Habitat Utilization, and Reproductive Patterns in *Caulacanthus ustulatus* (Caulacanthaceae, Gigartinales), a Newly Established Seaweed on Southern California Shores

Kim E. Whiteside and Steven N. Murray
California State University, Fullerton

INTRODUCTION

Marine communities around the world are experiencing shifts in community composition due in large part to human-mediated disturbance (Fields et al 1993, Harley et al 2006). Pollution, coastline modification, increased global warming, collecting and trampling by seashore visitors have all resulted in dramatic changes in species composition and thallus size structure over the last several decades (Murray et al 1999). Southern California, in particular, has experienced large population increases, which have put pressure on local marine communities (Murray et al 1999). Since the 1950s researchers have followed intertidal algal community composition as a means of detecting human-induced changes on marine ecosystems (Dawson 1959, Dawson 1965, Widdowson 1971, Littler & Murray 1975, Thom & Widdowson 1978, Murray et al 2001). In areas where pollution is high, researchers have found that large fleshy algae have decreased in percent cover, while more resistant crusts, coralline algae, and turf species have increased (Murray & Littler 1984). High human visitation has been correlated with decreases in the size structures of seaweed populations (Murray et al 2001) and is linked to shifts in species composition (Bullard 2005). Furthermore, human activities such as boating and aquarium keeping have resulted in increases in the presence of introduced species in southern California waters (Frisch 2003). In 1970, *Sargassum muticum* was recorded on Santa Catalina Island and by the following year could be found throughout Orange and San Diego Counties (Abbott & Hollenberg 1976). Recently, reports of species previously unknown or ignored in southern California have increased with the spottings of *Undaria pinnatifida*, *Lomentaria hakodatensis*, *Caulerpa taxofolia*, and *Caulacanthus ustulatus*, which have made their way to local waters within the last decade (Miller 2004). *Caulacanthus ustulatus*, a cryptogenic red seaweed, was first recorded at Corona del Mar, Orange County, in 1999 (Goodson 2003). Researchers saw an increase in the cover of this species (Murray pers comm.), but little was known about the ecology and extent of its distribution on southern California shores. This study examines the current distribution and abundance of *Caulacanthus* at both spatial and temporal scales. Additionally, in order to understand how southern California populations of *Caulacanthus* reproduce and disperse, we examined the phenology of this species.

MATERIALS & METHODS

World distribution

The worldwide distribution of *Caulacanthus ustulatus* was compiled from 2003-2007 using 152 herbarium specimens and 123 published literature references. Information on the 152 herbarium specimens was collected from the herbaria at UC Berkeley (UC), University of Michigan (MICH), and the Smithsonian Institution (SHUS). Literature references were collected through the use of internet searches, library search engines, and perusing the bibliographies of key papers on seaweed distributions. Data gathered from the herbarium collections and literature were used to plot *Caulacanthus* occurrences in order to provide an up-to-date map of the geographic distribution of this species. Information on introduced populations and the recorded reproduction condition of natural populations was also collected.

Southern California Distribution and Abundance

To determine the distribution of *Caulacanthus* in southern California, rapid-assessment surveys were conducted from November 2004 to June 2007 from Santa Barbara County to San Diego County, California. Thirty rocky intertidal sites, five from each of six southern California counties, were randomly chosen from 72 sites, which have historical floral information (Dawson 1959, Dawson 1965, Widdowson 1974, Thom 1976, Thom & Widdowson 1978). Several of these sites continue to be monitored by the Multi-agency Rocky Intertidal Network (MARINe). Sites were searched for 20-30 min, if *Caulacanthus* was present, its cover was estimated over100 m of coastline where the species was most abundant. Cover was estimated in 20 m sections using a modified Braun-Blanquet scale (0 = absent, 1 = present or >1%, 2 =1-5%, 3 = 5-10%, 4 = 10-25%, 5 = 25-50 %, 6 = <50%). These 20-m estimates were then averaged to determine the overall site rank in terms of *C. ustulatus* abundance. Voucher specimens were collected for later deposition at the UC Herbarium at Berkeley and for additional phenological and morphological examination.

Local Site Abundance and Distribution

To determine local site abundance and distribution we calculated the percent cover of *Caulacanthus* along permanent transects (31-42 m in length) from January 2003 to June 2006 at rocky intertidal sites at Corona del Mar and Dana Point in Orange County. Macrophyte cover and habitat utilization were determined using a point contact methodology at 10 cm intervals along each transect line. Species cover was determined by identifying all algal species to the lowest possible taxon for each contact point. Habitat utilization was determined by identifying the substratum utilized by *Caulacanthus*, including other living species. Tidal heights were taken at 1 m intervals along each line in order to plot species cover as a function of tidal height. The tidal interval means were then averaged to estimate overall site abundance. To examine habitat utilization available substratum and *Caulacanthus* utilization were analyzed using an electivity index (Krebs 1989). This ensured that we accounted for the availability of a particular substratum type.

$$\text{Electivity Index} = \frac{(P_{use} - P_{available})}{(P_{use} + P_{available})}$$

Morphology and Reproduction

Morphologies of specimens collected from five individuals from each of 15 sites ranging from Rueben Tarte Park, Washington, USA to San Quintin, Baja California, Mexico, were compared using three morphological characteristics. Individuals were chosen randomly along a 100 m of coastline and preserved in 4 % formalin seawater for later examination under a stereomicroscope. For each thallus, measurements were taken on five randomly chosen sections. On each section the following measurements were made: the number of branches within a 1 cm section of thallus, branching distance, and thallus diameter. Measurements were compared with data from the scientific literature using principal components analysis (PCA) to determine which of the measured characteristics contributed to the overall similarity/differences between geographic areas.

Seasonal variation in the phenology of *Caulacanthus ustulatus* was determined from February 2006 to February 2007 by examining specimens collected monthly from Crystal Cove and Dana Point in Orange County, California. Twenty-five specimens were randomly collected along five permanent transect lines established at each site. Samples were transported to the lab and preserved in 4 % formalin seawater until examination. For each individual, 1 g (wet weight) was examined for reproductive material using a stereomicroscope. Tetrasporophytes, carposporophytes, and gametophytes were identified when present using descriptions from Choi et al (2001). Average monthly temperatures from NOAA offshore buoys were compared with the reproductive results to determine if temperature could be correlated with the seasonal development of reproductive structures.

RESULTS

World distribution

Caulacanthus ustulatus can be found everywhere from boreal regions to the tropics; in mangroves, brackish waters, and coastal intertidal habitats. The species is located within nineteen biogeographic regions (adopted by the Smithsonian herbarium): Japan, Pacific Ocean Terrestrial, North Pacific Boreal, North Pacific Temperate, Gulf of California, Central American Terrestrial, Southeast Pacific Temperate, Fuegian, Tropical West Atlantic, Eastern South America, West Indies Terrestrial, Boreale, Lusitania, Mediterranean, Tropical East Atlantic, Cape, Indo-west Pacific, Indian Ocean Terrestrial, an New Zealand. Introduced populations have been recorded in Roscoff, France (Rueness & Rueness 2000), Prince Willliam Sound, Alaska (Ruiz et al 2006), and Neeltje Jans, Netherlands (Stegenga et al 2006). Early reports of *Caulacanthus* in the Eastern Pacific describe a disjunct distribution with *Caulacanthus* populations reported in Washington and British Columbia and in Baja California (Dawson 1961, Dawson 1966), but with no mention of records from Oregon or California before 1987. The first record for California came in 1987, when Dr. Chris Kjeldsen reported *Caulacanthus* in Tomales Bay, California (Gabrielson et al 2004). Then in 1999 the species was reported for the first time in southern California from Corona del Mar, Orange County (Goodson 2003). Since that time the species has spread to other localities in the area and into some isolated northern California locations.

The species exhibits a tri-phasic life-cycle and like many red algal species not all phases are displayed throughout the species range. Herbarium specimens and literature sources point to populations often consisting solely of vegetative thalli or with vegetative thalli and some tetrasporophytic material present. Carposporophytes and gameotophytes appear to be found only in populations in the following biogeographic regions: Lusitania, Mediterranean, Cape, Indo-west Pacific, and New Zealand. In the Eastern North Pacific, the northern populations in Washington and British Columbia do not appear to be fertile, while material in Baja California contained tetrasporophytes.

Southern California Distribution and Abundance

Our surveys of 30 intertidal sites along with reports from other researchers showed that *Caulacanthus* is widespread along the southern California mainland from central Los Angeles County to San Diego Bay and on Anacapa and Santa Catalina Islands. Surveys from sites north of Paradise Cove in Los Angeles County to the Vandenberg Airforce Base in Santa Barbara County did not contain *Caulacanthus*. The next northern site on the California mainland where *Caulacanthus* appears is Hazards Canyon in Montana de Oro State Park in San Luis Obispo County.

Local Site Abundance and Distribution

Caulacanthus cover has been variable over the last four year ranging from a minimum intertidal cover of 2.2 % in the summer of 2006 to a maximum 9.8 % in the winter of 2003 at Corona del Mar and from a minimum of 7.3 % in the winter of 2003 to a maximum of 15.1 % in the summer of 2004 at Dana Point (Fig 1). While the cover at Corona del Mar, a high-use site, has seen decreases in cover over time; Dana Point, a low-use area, has seen higher cover in the later years of this study beginning in the summer of 2004. There does not appear to be a strong seasonal abundance signal at either site; however, Dana Point seems to show small winter decreases and summer increases. Examination of vertical distribution and microhabitat utilization show that *Caulacanthus* is more abundant in the mid-intertidal zone; within this zone the distribution differs slightly. At Corona del Mar, *Caulacanthus* is more often found from the +1 to +5 ft tidal range with relatively the same abundance across the interval and decreases significantly in the MLLW to +1 ft interval. At Dana Point, the species is distributed lower on the shore, from the +3 to +5 ft interval and the MLLW to +1 ft interval; the most utilized portion of the intertidal at Dana Point is the +1 to +3 ft tidal interval. At Dana Point, in the higher tidal intervals the available substratum is composed of large boulders that are most likely moved during heavy winter swells. Microhabitat data analyses revealed the high epiphytic tendency of this species. *Caulacanthus* was found growing on a multitude of living substrata more often than on rock surfaces. The living substrata utilized by *Caulacanthus* fell into five main categories: articulated corallines, barnacles and mussels, *Silvetia* and large brown seaweeds, and crusts. Both sites were similar except for *Silvetia* and large brown seaweeds, which were absent or scarce at Corona del Mar. Based on electivity calculations, barnacles and mussels were utilized more than any other substratum group, followed by *Silvetia* & large browns (Dana Point only), turf forming species, crusts, and finally articulated corallines.

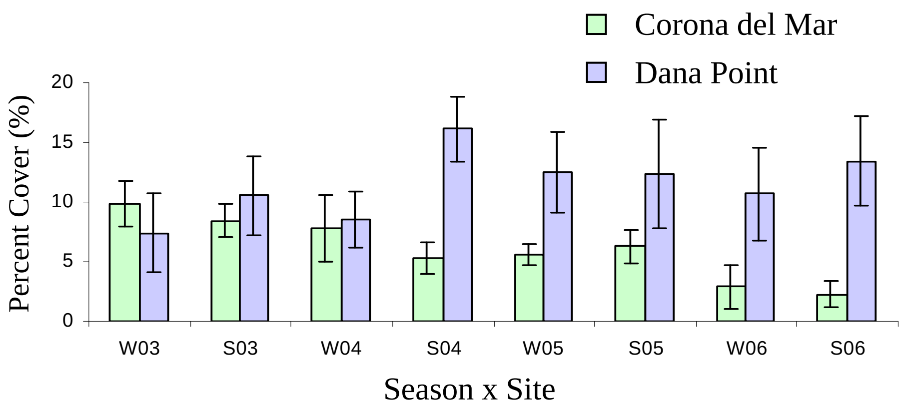

Fig. 1. *Caulacanthus* cover at Corona del Mar and Dana Point during winter (W) and summer (S) from 2003-2006.

Morphology and Reproduction

There are no results available at this time for the morphological portion of this study; this work remains in progress. All specimens are collected and are being examined. The reproductive portion of this study is also underway. Preliminary results, based on inspection of 300 samples from both Dana Point and Crystal Cove, reveal that only 7 specimens were reproductive – all tetrasporophytic; all remaining specimens were sterile. Three tetrasporophytes were found from Crystal Cove and four from Dana Point. Neither gametophyte nor carposporophyte material has been observed at either site.

DISCUSSION

Since its arrival 1999, *Caulacanthus* has spread along the southern California coast and become one of the major contributors to intertidal algal cover and primary production (Bullard 2005) l. Although, its origins are still uncertain, the historical disjunct distribution, the patchy spread of *Caulacanthus* along the California coast, its sudden increase in abundance, and the genetic alignment of southern California samples (Murray & Hommersand per comm.) with introduced specimens from Roscoff, France, and native Asia material strongly suggest that this species is an introduction. Further genetic work using microsatellites could resolve this question. Our microhabitat data show that *Caulcanthus* is spreading mostly through the mid-intertidal zone and will grow on almost any substratum (the species has even been found on the girdles of chitons). Lastly we conclude that the vast majority of *Caulacanthus* specimens in southern California are sterile with only a few being tetrasporophytic. This suggests that vegetative fragmentation is the most likely mode of reproduction and dispersal for this species, which is in line with expectations for many introduced seaweeds.

LITERATURE CITED

Abbott IA & Hollenberg GJ (1976) Marine Algae of California. Stanford Univ Press, Stanford

Bullard AM (2005) Macrophyte community structure and productivity of two southern California rocky shores. Calif State Univ, Fullerton MA Thesis

Choi HG, Nam KW & Norton TA (2001) No whirlwind romance: typhoons, temperature, and the failure of reproduction in *Caulacanthus okamurae* (Gigartinales, Rhodophyta) Eur J Phycol 36:353-358

Dawson EY (1959) A preliminary report on the benthic flora of southern California. In Oceanographic survey of the continental shelf area of southern California. Calif State Water Qual Control Brd 20:169-264

Dawson EY (1965) Intertidal Algae. In an oceanographic and biological survey of the southern California mainland shelf. Calif State Water Qual Control Brd 27: 220-231, 351-438

Fields PA, Graham JB, Rosenblatt RH & Somero GN (1993) Effects of expected global climate change on marine faunas. Trends Ecol Evol 8:362-367

Frisch SM (2003) Taxonomic diversity, geographic distribution, and commercial availability of aquarium-traded species of *Caulerpa* (Chlorophyta, Caulerpaceae) in southern Calfiornia, USA. Calif State Univ, Fullerton MA Thesis

Gabrielson PW, Widdowson TB & Lindstrom SC (2004) Keys to the seaweeds & seagrasses of Oregon and California: North of Point Conception. Phycological Contribution 6. p118

Goodson J (2004) Long-term changes in rocky intertidal populations and communities at Littler Corona del Mar, Calfornia: A synthesis using traditional and non-traditional data. Calif State Univ, Fullerton MA Thesis

Krebs CJ (1989) Niche Overlap and Diet Analysis. In Ecological Methodology. Harper & Row Publishers, New York. p394

Harley CDG, Randall Hughes A, Hultgren KM, Miner BG, Sorte CJB, Thornber CS, Rodriguez LF, Tomanek L, & Williams SL (2006) The impacts of climate change in coastal marine systems. Ecology Letters 9:228-241

Littler MM & Murray SN (1975) Impact of sewage on the distribution, abundance, and community structure of rocky intertidal macrophytes. Aquat Bot 7:35-46

Miller KA (2004) California’s non-native seaweeds. Fremontia 32(1):10-15

Murray SN & Littler MM (1984) Analysis of seaweed communities in a disturbed rocky intertidal environment near Whites Point, Los Angeles, California, USA. Hydrobiologia 116/117: 374-382

Murray SN, Ambrose RF, Bohnsack JA, Botsford LW, Carr MH, Davies GE, Dayton PK, Gotshall D, Gunderson DR, Hixon MA, Luchenco J, Mangel M, Mac Call A, McArdle DA, Ogden JC, Roughgarden J, Starr RM, Tegner MJ & Yoklavich MM (1999) No-take reserve networks: Sustaining fishery populations and marine ecosystems. Fisheries 24:11-25

Murray SN, Goodson J, Gerrard A & Lucas T (2001) Long-term changes in rocky intertidal seaweed populations in urban southern California. J Phycol 37(Suppl)

Rueness J & Rueness EK (2000) *Caulacanthus ustulatus* (Gigartinales, Rhodophyta) Brittany (France) is an introduction from the Pacific Ocean. Cryptogamie Algol 21(4): 355-363

Ruiz GM, Huber T, Larson K, McCann L, Steves B, Fofonoff P & Hines AH (2006) Biological invasions in Alaska's coastal marine ecosystem: Establishing a baseline. Report submitted to Prince William Sound Regional Citizen's Advisory Council & US Fish & Wildlife Service

Stegenga, H.; Draisma, S.; Karremans, M. (2006).*Caulacanthus ustulatus*: een nieuwe invasiesoort opNeeltje Jans. [*Caulacanthus ustulatus*: a new invasive species at Neeltje Jans (Netherlands)]. Het Zeepaard66(3): 79-82.

Thom RM & Widdowson TB (1978) A resurvey of E. Yale Dawson's 42 intertidal algal transects on the southern California mainland after 15 years. Bull S Cal Acad Sci 77:1-13

Widdowson TB (1971) Changes in the intertidal flora of the Los Angeles area since the survey by EY Dawson in 1956-1959. Bull of Calif Acad Sci 70:2-16