BLACK ABALONE MORTALITY:
Establishing a Research Agenda

Summary of a Workshop
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INTRODUCTION

In October 1988, the University of California Cooperative Extension/Sea Grant Extension Program (UCCE/SGEP) and the California Department of Fish & Game (CDFG) held a joint meeting on the black abalone *(Haliotis cracherodii)* mortality problem (or "the withering syndrome") then occurring at the Northern Channel Islands and Diablo Cove, San Luis Obispo County.

Prior to this meeting, commercial fishermen and others (notably researchers and fishery managers) had expressed concern about observed massive mortalities of black abalone, and the National Park Service (NPS) had reported severe declines in black abalone populations at the northern Channel Islands.

As a result, commercial red abalone aquaculturists were beginning to experience difficulties in exporting their products, while resource managers from other areas were expressing concern about the unknown cause of the mortalities and the possible association with imported reds. The 1988 meeting represented the first informational exchange between the industries, agencies, and researchers.

Following this meeting, several research projects were initiated to look more closely at the syndrome. However, the decline continued at the original sites, and additional declines were detected at islands where the mortality problem had not previously occurred. Furthermore, research efforts were not able to determine any definite causative agent for the mortalities. As a result, representatives from UCCE/SGEP, CDFG, NSP, and members of the CDFG Abalone Ad Hoc Committee decided that another workshop was needed.

Accordingly, a panel of scientists was identified to participate in a one-day workshop at the University of California, Santa Barbara, in September 1991, to review the status of black abalone populations, discuss research findings, and develop recommendations on future research areas. Panelists included those who had been documenting the decline and researching the cause, other experts in marine biology, physiology, and ecology, and industry and sport representatives. In addition, industry members and scientists with knowledge of abalone biology or invertebrate population declines were invited to participate.

The first half of the workshop included presentations on the history of abalone declines, and research on the cause of the current mass mortalities. Following these presentations, panelists discussed probable causes for the mortalities. Observations and research findings were also described.

The second half of the workshop was devoted to two discussions. A research subgroup focused on issues identified as being critical to understanding the withering syndrome. This subgroup developed key questions and possible research strategies. A management subgroup addressed the question of what management actions could be taken to conserve abalone resources and maintain or restore productive fisheries and mariculture businesses in California.

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BACKGROUND INFORMATION

Welcome

John Richards (UCCE/SGEP), workshop coordinator, opened with a brief description of the 1988 black abalone mortality meeting. He referred panelists and participants to the results of a survey that had been conducted in the summer of 1991 (see appendix). The survey was compiled to help distil what was known about the black abalone population declines, to summarize research efforts, to allow input on probable causes, and to allow for general comments from industry members, researchers, and the general public. Following introduction of the panelists, Alana Knaster, workshop moderator, reviewed the agenda.

History of the Problem

Earl Ebert, CDFG, provided a brief history of abalone mass mortalities in California. Mass mortalities of abalone in California and worldwide are rare. A massive die-off of red and black abalones occurred in 1906 along the San Luis Obispo County coast, near Morro Bay. It was reported at the time that "the sea bed was coated with a greasy slime of a supposed bituminous character which had killed the abalones. Abalones were found in abundance for miles along the shore, reds and blacks, but all were dead" (*Nautilus*, Vol. XX). The die-off was attributed to the San Francisco earthquake.

During the 1957–59 El Niño event, abalones along the Southern California mainland were often observed in a weakened, shrunken condition, but no mass mortalities were reported. Shrunken black abalones observed near White's Point, Palos Verde Peninsula, presumably resulted from starvation.

In addition, during the 1982–83 El Niño event, David Leighton reported a rather extensive mortality of black and green abalone in the San Diego region. A disease called pedal necrotic disease (PND) was identified as the cause. Abalone with PND presented symptoms quite unlike those now observed in withering-syndrome-infected abalone. PND symptoms included: (1) weakening and loss of purchase on the substrate, (2) darkening (deep brown to black) of the sole of the foot, (3) apparent necrosis or rotting of the sole of the foot with progression into the overlying muscle tissue, and (4) death of the abalone. Unlike the present symptomology, there was no apparent weight loss or shrinkage of the soft parts.

According to commercial abalone divers, the present the withering syndrome began in 1984. CDFG was first apprised of it in November 1987 by Gary Davis, chief biologist at the Channel Islands National Park. At the time, the withering syndrome was

particularly evident along the south side of Santa Cruz Island and at Anacapa Island. In June 1988, Pacific Gas and Electric Company (PG&E) biologists notified the CDFG that black abalones in the discharge cove at Diablo Canyon were experiencing a mass mortality of unknown cause. They described the abalones as undergoing a "wasting" process; abalones held in the laboratory had shrunken to such an extent that they could not attach to substrates. This process took about four weeks.

With reports of black abalone mortalities becoming more public, aquaculturists began to experience some difficulties in shipping *red* abalone (both seed and restaurant product) out of California. This industry has continued to be impacted despite the present lack of knowledge about the cause of the withering syndrome in black abalone and the lack of association with red abalone.

In response, UCCE/SGEP and CDFG convened an abalone mortality information meeting in 1988 to determine what was known about the syndrome. Two months later, the CDFG prepared an Issue Memorandum, strongly advising that black abalone taken from affected areas not be transported in flow-through holding tanks. Since the Department was uncertain as to whether an infectious agent was involved, the CDFG developed this measure in hopes of eliminating any possible mixing of water from affected areas and apparently healthy areas. The CDFG also hired a shellfish pathologist, Dr. Carolyn Friedman, to assist in efforts to understand the cause of the syndrome. Since that time, research efforts have been reviewed at semiannual meetings of the Abalone Ad Hoc Committee, but the cause of the withering syndrome is still unknown.

Review of Research

Dr. Carolyn Friedman, CDFG, reviewed information on research conducted by many research institutions and organizations on the recent die-off of black abalone. All of the following have been involved in documenting or researching the current problem: CDFG; Channel Islands National Park Service; Pacific Gas & Electric; Tenera; University of California, Davis; Bodega Marine Laboratory; University of California, Santa Barbara; Oregon State University; University of California, Santa Cruz; the Ab Lab; the Abalone Farm; McCormick & Associates; Washington Department of Shellfisheries; British Columbia Ministry of Fisheries and Oceans; U.S. Fish & Wildlife Service; the U.S. Navy; and the NOAA Sanctuary Program (Gulf of the Farallones National Marine Sanctuary and the Channel Islands National Marine Sanctuary). In addition, the California Abalone Association and several commercial and sport abalone divers have provided

information and collected moribund abalone for analysis. Many of the studies were the result of collaborative efforts by several of these groups.

Clinical Symptoms of the Withering Syndrome

Early detection of diseased or affected animals has not been possible to date. Clinical symptoms of abalone with the withering syndrome can only be identified when the animal is in the advanced stages of the disease. These symptoms include: discoloration, decreased weight, so that the foot and viscera do not fill the entire cavity of the shell; weakness (abalone can often be easily removed from the substrate by hand); decreased tactile response; and death.

Observations of the withering syndrome have been reported for all sizes of abalone. Black abalones are the only species that are known to suffer from this syndrome, though other species of abalone have been observed with similar clinical symptoms. It should be noted, however, that the symptoms of the withering syndrome are a generalized response to any long-term stress in abalone. For instance, starving abalone shrink, but this condition is reversible (i.e., abalone gain weight back when fed). On the contrary, the shrunken condition has not been found to be reversible in animals with the withering syndrome. As a result of the subtidal habits and comparatively low population densities of the other abalone species in California, study of these species has been very limited.

Research Projects

Coccidian Parasite. Initial investigations by researchers at the CDFG, NPS, and UC Davis, concentrated on testing the hypothesis that a renal coccidian parasite was associated with the die-off.

Field studies were conducted in which black abalone were randomly collected from several sites at the Channel Islands. Other species of abalone were also sampled from these islands. Animals were examined several times during 1988, 1989, and 1990. Five species of abalone from California (black, red, green, pink, and pinto), two species from Baja, California (black and green), two species from Oregon (pinto and flat), and one species from Washington state and British Columbia (pinto) revealed that the coccidians occur in California animals examined regardless of species or health. Approximately 69% of all abalone samples from California had renal coccidian infections. Animals from Baja did not contain coccidia, although only a small sample was examined. The parasites were not observed in any abalone from Oregon, Washington, or British Columbia. Statistical analysis of these data indicated that no clear association existed between

intensity of coccidian infection (number of coccidians/field of view) and condition of the hosts (measured as total weight – shell weight/total weight).

UC Santa Barbara researchers also sampled populations of black abalone from the Channel Islands and examined the animals for coccidian infections and condition using a multivariate statistical analysis. Although originally they had not observed a clear association between coccidian infection and the withering syndrome, they later found that there may be some association.

Laboratory studies in which coccidian-free pinto abalone from British Columbia were injected with crude homogenates of infected kidney tissues did not result in infection, and no mortality resulted from the experimental procedures. Transmission studies initiated in September 1990 in which coccidian-free pinto abalone are cohabiting with infected *red* abalone are ongoing. As of June 1991, the pinto abalone had not become infected. Pinto abalone from central California and the Farallon Islands have been observed with coccidian infections.

Juvenile abalone have not been observed with coccidian infections until they reach a size greater than 1 cm. Whether transmission is direct or indirect is not known. However, all stages of the parasite, both sexual and asexual, appear to be present in individual abalone, which suggests that direct transmission may be possible.

Drug trials, using Romet-B (a coccidiocide) in an artificial abalone diet, have just been completed. The drug did not appear to be effective.

Further studies of this parasite are needed to determine whether the coccidians observed in the different species of California abalone are identical. The parasites appear very similar with respect to morphology, tissue specificity, and host response in all species of abalone examined.

Influence of Temperature and Food. The influence of water temperature and food availability on the survival of abalone from a population with the withering syndrome was investigated. Black abalone were collected from an area on Santa Rosa Island, adjacent to a site where the abalone were undergoing the withering syndrome. After a 3-week acclimation period, the abalone were maintained under one of four temperature and feeding regimes. Animals were held at 13° and 20°C. Animals in two tanks at each temperature were starved, and those in the other aquaria were fed to satiation. All of the abalone at 20°C died, while approximately 8% of the abalone held at 13°C survived. Although overall survival rates were not high in the 13°C experiment, the rates of mortality were significantly different between the two temperature regimes. At the lower temperature, a steady, slow decline of animals occurred over a 20-week period. In contrast, the rate of mortality was faster in the 20°C aquaria, with a rapid decline starting

only one week after exposure to the temperature, and tapering off after 10 weeks. Microscopic analysis of all surviving and dead animals suggested a slight inverse relationship between coccidian infection and temperature.

Diablo Cove researchers conducted extensive field studies to determine the scope and pattern of mortality within the cove and surrounding areas. Mortality was higher in the areas of the cove that were exposed to thermal effluent from the Diablo power plant. However, abalone to the north of Diablo Cove that are not exposed to elevated water temperatures have also shown evidence of the withering syndrome. Laboratory experiments resulted in findings similar to those observed in the CDFG studies: higher temperatures resulted in an increased mortality rate, and microscopic analysis of abalone kidneys found coccidians present. [Microscopic analysis was completed using only six to eight survivors from each of the three experimental temperatures, ambient (10° to 14°C), 16°C, and 18°C].

An interesting observation from the study conducted at Diablo related to animals fed well at all experimental temperatures: those held at the highest temperature (18°C) appeared to be incapable of completely digesting kelp. This was evidenced by large amounts of undigested kelp in their feces. In contrast, abalone held at ambient temperatures (10° to 14°C) appeared to fully digest kelp. Findings from this experiment, conducted in 1989, conflict with thermal tolerance experiments conducted on black abalone at the Diablo laboratory in the late 1970s and early 1980s. In those studies the observed thermal tolerance of animals from the coastline surrounding the Cove ranged from 26°C to above 28°C, depending on acclimation temperature. This recent decreased temperature tolerance was also observed for black abalone from Santa Cruz Island.

Respiration. The researchers from Diablo Cove also measured oxygen consumption of healthy and moribund black abalone and respiration of exposed and submerged abalone. Abalone with the withering syndrome had oxygen consumption rates 2 to 2.5 times higher than those of apparently healthy abalone. Exposed abalone had decreased respiration rates compared to submerged abalone.

Analysis of Heavy Metals and Other Pollutants. A few abalone samples were submitted to the CDFG pollution laboratory to assay for chlorinated hydrocarbon (CH) pesticides and heavy metals. Samples from 1988 and 1989 showed no such pesticides. The 1988 samples showed sublethal levels of a few heavy metals including zinc, lead, chromium, and mercury. The 1989 samples were not analyzed for heavy metals. The Diablo Canyon group also analyzed water samples and found no pollutants in Diablo Cove.

Ongoing Studies

Several other research studies have been funded. These are collaborative projects involving the CDFG, NPS, UC Davis, UC Santa Barbara, UC Santa Cruz, the U.S. Navy, and NOAA.

GIS. A Geographical Information System (GIS) relating to the withering syndrome will be developed. By integrating data on environmental factors and data on the black abalone population declines at the Channel Islands, spatial and temporal patterns will be analyzed.

Translocation. Black abalone from apparently healthy populations will be translocated to areas where the withering syndrome is active and to areas where it has nearly depopulated an island. The purpose is to determine whether the etiological agent of the withering syndrome is still present in these areas and to document the course of the disease from a known time of introduction into infective waters.

Physiology. Black abalone from affected and unaffected populations will be collected, and various metabolic processes will be measured in order to determine baseline physiological parameters of healthy versus moribund abalone.

Blood Chemistry. Evaluation of hemolymph characteristics of healthy and moribund black abalone. The study can be done in conjunction with the physiological analysis.

In general, Friedman felt that less attention will be given to the renal coccidian parasite, which was initially believed to be a primary factor of the withering syndrome. Instead, the research focus will include broader experimental approaches. In particular, more basic information regarding black abalone physiology and the ecology of the Channel Islands and mainland coastal habitats will be sought.

PANEL DELIBERATIONS

The remainder of the session was designed to obtain input from the panel on the following question: Given research findings to date and the current base of knowledge on the withering syndrome, what areas warrant additional investigation?

Areas That Warrant Investigation

Panel members agreed that a combination of factors is probably causing the withering syndrome. Stress, induced by elevated water temperatures, lack of food, hypersaline conditions, or higher population densities, appears to be associated with the mortalities. The factors that follow (not prioritized) were identified as possible contributors to the syndrome.

Coccidian Parasite. Recent findings may better define the relationship between this parasite and the syndrome. UC Santa Barbara researchers have found a slight correlation between the number of coccidian cells per abalone and mortality at different locations. (At San Nicolas, where the withering syndrome has not been found, and at Santa Cruz, where the withering syndrome seems to have subsided, coccidian infections are low. However, at San Miguel, where mortality due to the withering syndrome is still occurring, high intensities of this parasite were found). UC Santa Barbara researchers have also found a slight, but significant correlation between intensity of coccidian and pathology of the abalone. It was suggested that even though every abalone has coccidians, a cofactor such as stress may cause the number of parasites to increase and eventually result in death of the abalone.

These findings differ from results of other investigations. In addition, one aquaculturist reported that a high level of coccidians was found in a large, fast-growing, apparently healthy *red* abalone. It was suggested that a search for animals collected prior to 1984 be initiated. These animals could be examined to establish what, if any, levels of coccidians occurred prior to the appearance of the withering syndrome.

One further note was made: In South Carolina, a similar relationship between stress as a cofactor and increasing lethal parasite intensities has been seen. Oysters (*Crassostrea virginica*) that carried a specific parasite did not experience mass mortalities until water temperatures became elevated by a few degrees and/or the salinity changed.

Elevated Temperatures. Water temperature increases have caused stress to abalone both in the laboratory and the field. In the laboratory, a small percentage of red abalone exhibit symptoms similar to the withering syndrome when exposed to elevated

water temperatures. In the field, spawning occurs during peak seasonal water temperatures. It was noted that during spawning periods (September to December), mortality rates of black abalone on Santa Cruz Island increased.

At Diablo Canyon, studies have shown a decreased thermal tolerance in black abalone. Animals tested at Diablo were not collected from the Diablo Cove study area, but from the surrounding 12 miles of coastline. Earlier experiments showed animals in this population could tolerate a temperature of 26°C, but now experience significant mortality levels at 18°C. This change in thermal tolerance has also been noted for blacks on Santa Cruz Island.

As a result of the fact that black abalone inhabit the intertidal zone, it was suggested that air temperature be considered in addition to water temperature.

Physiological Studies. The response of abalones to different stress factors can be tested using *in vivo* nuclear magnetic resonance spectroscopy (NMR) and gas chromatography. Completed NMR studies followed the time-course changes in energy compounds and intracellular pH in response to salinity variations in live abalone. NMR techniques can be used without killing the animal, and may be a good method for isolating how the withering syndrome is physiologically affecting the abalone. In addition, salinity changes, which may be a factor, can be studied using high-resolution gas chromotography. This method would allow a number of potential osmoregulatory compounds, such as glycine, to be monitored. Taurine levels, which regulate stress metabolism and are found in the gills of all mollusks, could also be examined using gas chromatography.

Salinity. The CDFG has taken a preliminary look at the effects of hypersaline conditions on abalone. It is believed by some researchers that saline levels in intertidal areas may have been extraordinarily high as a result of many years of drought. Not only has there been less precipitation, but with increased amounts of sunlight, evaporation may have caused intertidal microhabitats to go into a hypersaline condition. It was noted that very sunny, dry areas were the first to be hit with the withering syndrome.

Viral and Bacterial Causes. Preliminary examinations by George Gardner from the U.S. Environmental Protection Agency revealed that the withering syndrome may be due to a protozoan. However, other preliminary investigations have not found any obvious "infectious agent." Nonetheless, the withering syndrome seems to be spreading both north and south, which suggests that a biological agent rather than a physical agent may be involved, although no conclusive evidence exists.

Pollution. Heavy metals or other pollutants do not seem to be involved. However, it was noted that the Navy had closed off the south side of Santa Cruz Island in 1984–

85 to conduct tests, and perhaps introduced something that caused the withering syndrome to begin. Also, an oil platform was being towed up and down the coast, near the islands, during this period; it was suggested that something may have been introduced via ballast water.

Food. The relationship between the withering syndrome and food availability and quality was discussed. It was agreed that the amount and quality of kelp did decrease as a result of the 1982–83 and 1986–87 El Niños and that low food abundance may have contributed to the initial onset of the mortalities. However, the withering syndrome is still occurring, and kelp beds have been very healthy and abundant for the past few years.

Also, preliminary investigations of laboratory-held red abalone exhibiting the withering syndrome-type symptoms revealed the presence of sponge spicules in the abalone's gut. It was suggested that ingestion of this or other toxic algae or animals, which had become more abundant with elevated water temperatures, may be responsible for the withering syndrome. In an experiment in which *red* abalone were injected with ground-up sponge, two of three animals died, whereas the control group, which received injections of water, exhibited no ill effects.

Molecular Factors. Molecular approaches were suggested as means of looking for a probable cause of the withering syndrome. For example, Japanese research suggests that highly inbred animals exhibit shrunken foot symptoms. If abalone larvae, which are short-lived in the plankton, were to settle within the population that spawned them, resulting inbred populations might exhibit some negative effects, such as intolerance to environmental changes or actual genetic diseases. Basic studies could help quantify the genetic diversity within and between black abalone populations. It was also suggested that the effect of coccidian infections on the immunological defense system of the abalone should be explored. In addition, since animals with the withering syndrome do not move around and their mantle is retracted, there may be a breakdown in cell membrane function, or a chemical imbalance may be occurring in the nervous system.

Densities. Higher population densities may have led to the spread of the withering syndrome. Populations were extremely dense when the syndrome appeared. The rate of mortality on Santa Cruz Island was reportedly density-dependent.

Critical Research Needs

Several problems exist that make it difficult to determine the cause of the withering syndrome. Areas that need to be clarified include:

Diagnosis of the withering syndrome at an earlier stage. One can only detect an unhealthy abalone once the syndrome is well developed. Thus, it is difficult to know whether an abalone is healthy or whether symptoms have not yet shown up. A limiting factor is access to reliable stocks of "normal" or uninfected animals for comparison.

Determination of whether the symptoms reported for red *abalone from the field and laboratory are the same as those seen in black abalone in the field.* Many participants felt that black abalone are being exposed to something infectious. Questions arose as to why only a small percentage of *red* abalone in culturing systems (which would be much more sensitive to an infection) show symptoms similar to the withering syndrome. Until the association between the withering syndrome in blacks and the similar symptoms in reds is clarified, aquaculturists will continue to have problems exporting red abalone.

Correlation between mortalities north of Point Conception (e.g., Diablo Cove) and those at the islands is also needed. It appears that black abalones in and around Diablo Cove are undergoing the same problem as are island abalones.

Determination of the "normal" physiological state of black abalone. It is difficult to identify a virus or to determine whether stress is affecting osmoregulatory processes when molluscan cell lines are not available (save one [BGE-I], developed from the freshwater snail *Biomphalaria glabrata*).

Other Concerns

The issue arose of ethical ways to deal with the need to take abalones for research, given the extremely low population levels. It was stressed that techniques that can utilize live specimens in a nonlethal manner are needed.

In conjunction with this concern, the need for population modelling was discussed. Three questions were asked: How many black abalone currently exist? What is the reproductive effort of these remaining animals? Can the remaining animals reproduce enough to sustain or augment present population levels?

In 1988, black abalone at one site on Santa Cruz Island did not develop ripe gonads. In 1989, at the same site, two patterns of reproductive development were seen: some abalone put on a lot of gonadal weight; others did not, and the foot began to shrink. Furthermore, PG&E reported that normal methods of inducing spawning (UV-treated water and hydrogen peroxide) did not cause black abalone from Diablo Cove to spawn. Only two methods were successful, desiccation and thermal shock.

It was noted that in *red* abalone the gonads are reabsorbed when the animals become stressed. If black abalones also react in this manner, recruitment could suffer

greatly. However, recruitment on Santa Cruz Island was reportedly high in 1990–91. Thus, continued monitoring of the populations is critical, as new management strategies may become necessary if recruitment is impacted.

RESEARCH DISCUSSION

A subgroup of the panel later met with other conference participants to discuss research issues critical to understanding the withering syndrome. This subgroup developed the key questions listed below and identified possible studies that could be pursued to answer these questions.

Is there an infectious (transmittable) agent involved? Researchers agree that the withering syndrome seems to be spreading in a fashion which indicates that a biological agent is the cause. The coccidian parasite continues to be a possibility requiring further research. In addition, the following areas should be considered: (1) Define what is normal in healthy abalone; (2) Look for other parasites and/or agents (it may be that something very small is causing the problem, or that only certain early stages of the agent are present); (3) Determine which organs are affected and to what extent; (4) Determine if there is a subtle biochemical or molecular change (e.g., energy depletion); (5) Define effects on the central nervous system. If there are no histological changes, then perhaps the change is neurological or chemical.

Possible experimental procedures to determine whether an infectious agent is involved were suggested: (1) Put sick and well animals together (homogenize dead animals and inject well ones, or expose well animals to this slurry); (2) Start documenting changes from well to sick, using noninvasive techniques (e.g., blood chemistry, NMR, calorimetry) to analyze tissue, body fluids, blood, etc.; (3) Track stress-indicator compounds, such as inorganic phosphates, utilizing *in vivo* NMR.

In these experiments, only the effects would be documented, not the cause. In addition, controls establishing baseline physiology, at matching densities, are critical. Once it is known whether or not the withering syndrome is transmittable, then one could document relationships between certain variables (size, temperature, tissue makeup, etc.) if warranted.

Can comparisons be made between experiments utilizing abalone from different areas? Using abalone from different areas may be introducing different genetic variables. Panelists felt that two things should be done: (1) Take San Nicolas animals and let the Diablo Cove group run their temperature experiment (if healthy, the animals should not be affected at 18°C); (2) Run parallel experiments at different locations, testing waters from these areas.

What is the genetic impact or effect? Genetic studies comparing Mexican stocks to affected stocks and/or comparing San Nicolas abalone to other populations were

suggested. It was noted that if there are isolated populations, restoration efforts may lead to the re-evaluation of present management strategies.

If the withering syndrome is associated with a particular genetic marker, genetic studies may be able to identify populations at risk. This information would allow identification of potential donor populations for restoration of natural areas decimated by the withering syndrome.

To conduct a genetic study, random samples from different populations would be needed, taking 20 to 50 animals per population (or as many as funding for analysis would allow). Genetic comparisons should also be done on survivors from infected areas and animals with the withering syndrome.

What are the effects on the community dynamics at sites where the withering syndrome has decimated black abalone populations? Concern was raised as to whether anyone is monitoring changes to the areas where black abalone no longer exist. It was suggested that in conjunction with a translocation study, a study of community response to the removal of abalone should be conducted.

What can be done now to help evaluate the withering syndrome? Several investigations were suggested: (1) Laboratory analysis (biochemical) of tissues. These tests can analyze what is happening when the animals are stressed; (2) Transmissibility exercises between "good" stock and "exposed" stocks; (3) Continuation of ongoing field studies; (4) Ecological monitoring of the intertidal zone, looking at impacts on other species (i.e., is the withering syndrome affecting other populations?); (5) Continuation of studies at Diablo Cove; and (6) Continuation of attempts to culture black abalones, thereby providing animals for future testing and/or enhancement.

It was suggested that field researchers should make their data-collecting efforts conform. A monitoring protocol was discussed, involving collection of the following types of field data: individual growth rates, survivorship rates, patterns of movement, recruitment, density, generic energy budget, gonadal indexes, prevalence of the withering syndrome, and sex ratios.

MANAGEMENT SUBGROUP DISCUSSION

The management subgroup addressed the following question: What management actions need to be taken to conserve abalone resources and to maintain or restore productive abalone fisheries and mariculture businesses in California?

Given limited knowledge regarding the conditions of Southern California abalone populations and the causes of their collapse, this subgroup felt that management should proceed in three steps. First, actions should be taken to assess the situation and determine the nature and extent of the problem. Next, actions should be taken to stabilize the situation and prevent further damage. Finally, actions should be initiated to restore the situation to its previous productive condition.

Assessment of the condition of black abalone populations and effects on abalone culturists has begun, but additional information is required. Black abalone populations on five of the eight Channel Islands are monitored regularly by CDFG, NPS, the U.S. Fish & Wildlife Service, and (at the west end of Santa Cruz Island) by Dr. Brian Tissot. CDFG also monitors San Clemente Island and a site at Vandenburg Air Force Base. A survey of black abalone abundance, distribution, population size structure, and the occurrence of the withering syndrome is needed throughout Southern California to determine present conditions. A clearinghouse for information on population conditions from interested observers (e.g., commercial divers, recreational fishermen, and university scientists) could be established to supplement survey information. The Channel Islands National Marine Sanctuary and UC Santa Barbara researchers have begun to establish a geographic information system to organize and analyze information regarding both present and past population conditions.

Another element of this assessment should be identification and definition of management issues that can be used to prioritize research. For example, abalone culture businesses are currently hampered by uncertainty regarding the role of an infectious agent in the population declines. Until research rules out infectious agents as the cause of the mass mortality, abalone exports will be curtailed by market forces and governmental agencies. Another issue concerns the adequacy of existing management strategies to assure conservation of black abalone resources. Each of these issues affects a segment of the abalone industry and will dictate different kinds of research.

Actions to prevent further damage and to lay foundations for restoration efforts have begun. As a result of Assembly Bill 3705 (Hauser, Abalone), commercial harvest has been temporarily suspended at three of the Channel Islands where populations were already depleted (Santa Barbara, Anacapa, and Santa Cruz Islands), to protect survivors

and provide at least a limited reproductive capacity for future restoration and recovery. These areas may also serve as study sites for development and testing of restoration techniques. In addition, efforts to establish brood stock have been taken by the operators of two culture facilities (John McMullen, Ab Lab, Port Hueneme, and Tom McCormick, McCormick and Associates, Oxnard). These populations may provide abalone for experimental and wild-stock restoration.

The points of control for abalone resource managers are quite limited and do not appear to include factors most probably causing the mass mortalities: infectious agents and ecological conditions. Fishery harvest is a controllable factor. Even though harvest was probably not a major factor in recent declines, its modification offers an available action to protect survivors and assure reproductive capacity for the future. Recruitment enhancement with cultured abalone offers limited, but potentially useful, opportunities for restoration. Controls on water pollution are also of potential importance. Finally, it is possible to restrict the sale and transport of potentially infected or contaminated abalones.

SUMMARY

A panel of marine biologists, commercial and sport fishermen, and aquaculture industry representatives was assembled to review the black abalone mortality occurring in Southern California.

The panel concluded that a broader look at the mass mortalities was needed, as many co-factors (e.g., stress induced by other conditions) are probably involved. This approach will help identify the extent of damage and the cause of the die-off, and to help guide potential management decisions.

Although critical research areas could not be ranked, the panel felt that future endeavors should be focused on: infectious agents, physiology, diagnostic assays, and ecology (including monitoring, geographic information analysis, population genetics, and community dynamics and structure).

Management was also identified as a critical element for consideration. Abalone resource managers have addressed the crisis with most of the available tools. Initial assessments identified a serious problem, fishery harvest was suspended in heavily impacted areas, and efforts were taken to establish brood stocks in culture facilities. Additional attention should be directed to making a survey of the current conditions of black abalone populations throughout Southern California, and to developing a clear definition of management issues, prioritized to direct research efforts.

APPENDIX A
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Field & Laboratory Experiments

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APPENDIX B
Survey Results: Observations and Research On The Abalone Withering Syndrome

A total of 34 surveys were returned. Below is a compilation of the data gathered from the responses.

1) Have you observed the abalone withering syndrome (WS) in:

	Yes	No	Which Year(s)
the Field	23 (68%)	11 (32%)	See #3
the Lab	16 (47%)	18 (53%)	1972 - 1991

2) If yes, in what species did you observe it? (Please circle)

Blacks	Reds	Pinks	Greens
23	15	5	5

Whites	Pintos	Flats
0	1	0

NOTE: The majority of observations of WS in reds were reported for laboratory/aquaculture facilities (i.e few field observations).

3) If in the field, at what location(s) and what year(s) have you seen the 'syndrome'? (Please circle and indicate year seen at that site)

	Location	No. of Responses	Years
Coastal -	Baja	0	-----
	S.Diego	3	1987
	L.A.	2	84/85 & 90
	Ventura	1	1985
	San Luis	11	1988-91
	North of SLO	0	-----
Islands -	S. Miguel	5	1988-91
	S. Rosa	5	1986-91
	S. Cruz	9	1984-91
	Anacapa	6	1985-91
	S.Barbara	2	1991
	S. Nic	2	1990-91
	S. Catalina	0	-----
	S. Clemente	7	1989-91

4) If observed in the lab, can you associate the 'syndrome' with any other parameter in your system? (e.g. temperature change, food availability, aeration, seasonality, etc.)

*Stress Induced : Increased Temperature	7
High Densities (Crowding)	5
Poor Water Quality (Low DO)	2
Starvation	1
*Damage Due to Handling	2
*Bacterial Infection (Vibrio)	1

5) In the locations that you noted above, is the syndrome still occurring?

For those who said yes, date was extended to 1991 on question #3.

6) Have you seen declines of any other species which share the same habitat with black abalone?

No	31
Urchins (Heard about;not actually observed)	1
Mussel Beds (M. californianus) and	
Sea Stars (P. Ochraceus) - Pt. Loma 90/91	1
Possibly topshells & red urchins	1

7) There have been several hypotheses suggested as to the cause of the withering syndrome (WS). From your observations have you formulated any possible causes for WS? (Please list below)

Stress with associated decrease in resistance	
- Initiated by increase in temperature	5
- Initiated by starvation (loss of kelp beds & urchin overgrazing)	4
Infectious Disease (Stress induced)	7
Increased Salinity (as result of drought)	2
- Introduction of hypersaline virus\bacteria	1
Lack of Necessary Nutrients	
- Due to change in microalgae community	2
- Due to lack of runoff	1
Parasites, which manifest stressed animals	1
Genetic (High inbreeding)	1
Pollution - Air & Water	4
Overcrowding\High densities	1
Oil drill muds	1

8) If you have done research on this syndrome, what parameters did you monitor (e.g. densities, temperature, water quality, food availability, parasitic infections, transmittability, etc.) & what were the results?

Temperature (Tested by 3 groups)
- Elevated temperatures result in higher mortality rates.

Food Availability
- Food appears to affect survival of animals held in lower temperatures.
- Monitoring of drift kelp at Santa Cruz Islands (1987 - 1989) showed little was available and that growth of abalone declined to 0 mm\month (Sept. 1987 - March 1988).

Parasitic Infections
- Coccidians (Studied by 3 Groups)
  - Present in both healthy & sick abalone, as well as in all species of abalone found in California, with no correlation between intensity & condition of the animal.
  - Small abalone (<1 - 1.5 cm) have been free of coccidians.
  - Appears to be an inverse relationship between coccidian intensity and temperature.
  - Currently looking at transmission of the coccidian.
- Nematode Larvae
  - Encysted larvae has been found in samples from San Clemente but at very low prevalence & intensities.
- Pycnogonids
  - Have been found on abalone from Santa Cruz Island. They appear to feed on the tissue thus may be a possible disease vector.

Growth Rates
- Lower growth rates of animals in affected areas vs. unaffected

Pathology
- Determined pattern of pathology

Physiology
- Looking at blood chemistry vs. animal condition

Densities

9) What are your concerns about WS? How has it affected you?

Species may go extinct	10
Affecting Abalone Aquaculture Industry	
- Sales of Abalone	5
- Outplanting of Abalone	1
May start to affect other organisms	5
- May contaminate culture stocks	4

Affecting Commercial Fishing Industry - Harvest of Abalone	6
Unclear if Diablo Canyon Problem is the same as the overall "Islands" problem	1
Concerned that causative agent may be incorrectly identified and then management decisions will be based on the findings	1
Spreading at San Nicolas may delete populations of abalone and negatively affect translocated sea otters & research	1

10) Given the current limited research funding situation, what are the **THREE** most important areas/issues regarding WS which you feel should be pursued?

Isolation of Causative Agent	12
Physiological testing (to differing conditions)	10
Transmittability	7
- Intra- & Interspecific	4
Coordination of existing data to recreate history & pattern of mortality (look at temperature, algal blooms, kelp availability, currents, pollution etc.)	4
Investigate ecological impact with loss of this important invertebrate	5
Continue monitoring populations (recovery vs. persistence of WS in affected areas)	3
Protect remaining population\alter mgmt schemes	2
Define disease syndrome	2
Examine replacement of blacks in areas with former populations	2
Check condition of stocks in Mexico	1
Analyze historical data on similar problems	1
Test the following conditions\variables:	
Nutritional requirements (Immunodeficiency)	3
High Temperature	1
Juvenile vs. adults	1
Healthy vs. unhealthy	1
Viral Bacteria	1
Test antiviral & antibiotic drugs for their effectiveness in changing the course of the disease	1
Sponges	1
Salinity	1
Pesticides	1
Heavy Metals	1
Toxics (oil)	1
Genetic Component	1
Role of coccidian in stressed abalone	1

11) Are you aware of any researchers that may be interested in this problem?

Persons listed were sent an invitation to the meeting.

12) Do you know of any potential sources of funding for research on WS?

Dept. of Fish & Game\Fish & Game Commissions\Sea Grant\ National Parks Service\National Marine Sanctuary\Biosphere Reserve\NIH\NSF\U.S. Dept. of Ag\WRAC\NOAA\Global Warming Program\Electric Power Research Inst.\S.B. Cnty Oil Funds\ AB 3705 (Tax for abalone enhancement)

13) Are there any publications pertinent to WS of which panelists should be aware? (Please list)

List available through the Santa Barbara Sea Grant Ext. Office.

Additional Observations\Comments

A disease (Pedal Necrotic Disease -PND) was observed in abalone off south La Jolla in 1982-83. However, abalone with this PN disease presented symptoms quite unlike those now observed in WS-infected abalone.

Commercial fishermen, who were first to report the decline in black abalone populations, state that the syndrome began on the backside of Santa Cruz. They report that currently the only unaffected areas are the inside of San Miguel and the inside of San Nicolas Islands.

THANK YOU FOR CONTRIBUTING TO THIS SURVEY!

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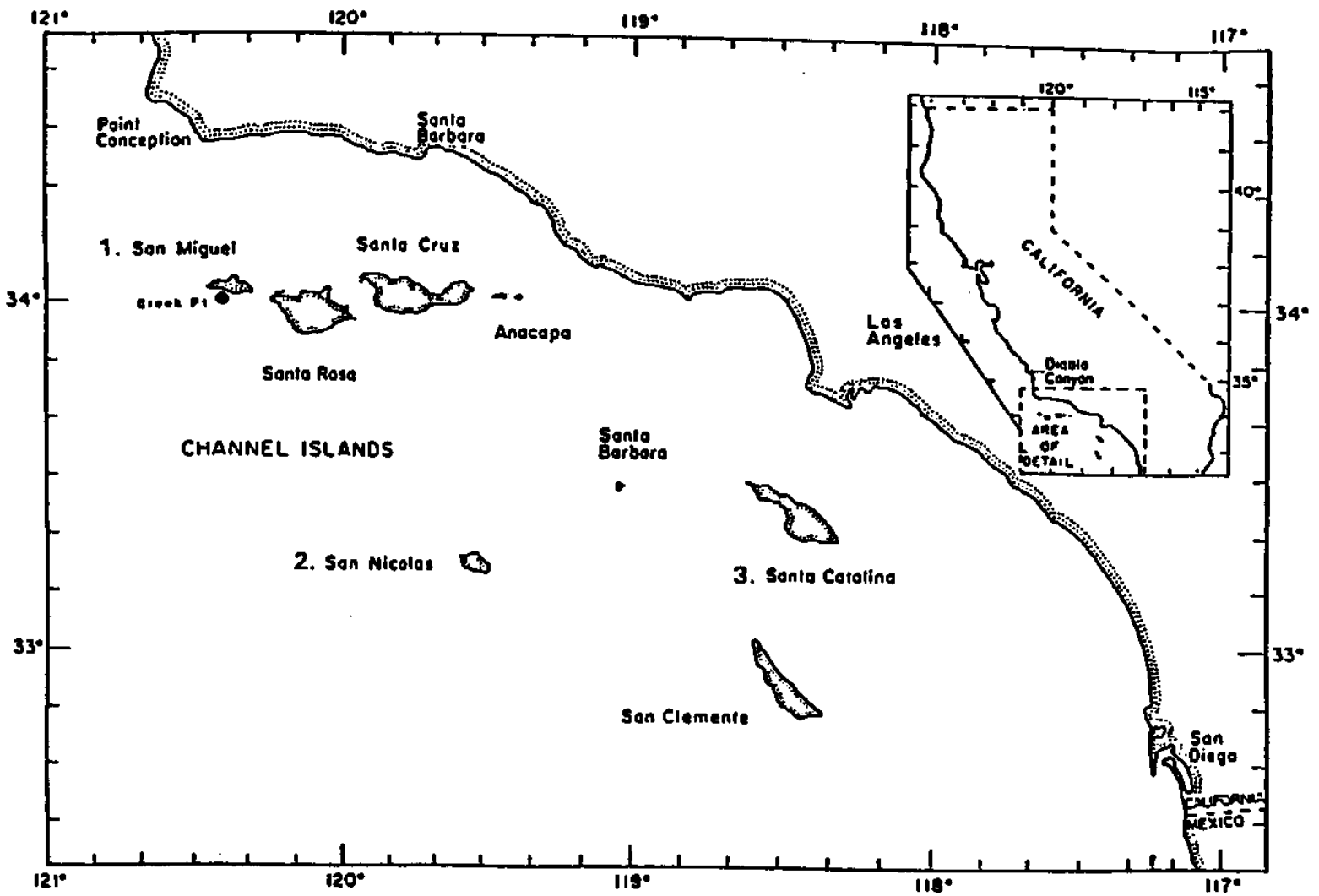
APPENDIX E
The Channel Islands and Diablo Canyon:
Documented Areas of the Black Abalone Withering Syndrome (Exceptions Noted)



The withering syndrome has been documented at all the Channel Islands and at Diablo Canyon, with the following exceptions:

1. Animals with the withering syndrome found only at Crook Point, as of 9/91.
2. No occurrence of the withering syndrome at this Island, as of 9/91.
3. Samples taken in 1989 showed no occurrence of the withering syndrome.