STATEWIDE STRATEGIC CONTROL PLAN FOR APPLE SNAIL (*Pomacea canaliculata*) IN HAWAI'I

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produced by

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me ka ha'a ha'a,

Penny Levin

Executive Summary

Thousands of acres of kalo (taro) once supported a thriving Hawaiian population prior to the arrival of Captain Cook. There are now only an estimated 500 acres remaining in cultivation in the State of Hawai'i. As a crop, taro was worth $2.2 million in 2005 and produced 3.75 million pounds of poi; 1.56 million meals on tables in the state or 16,250 families benefiting from taro in their diets all year round. Taro is also, by far, the most culturally significant crop in the islands. It holds a sacred place, as elder brother, in the genealogy of the Hawaiian people. It remains a central image in the identity of every Hawaiian. The beauty of lo'i kalo (wetland taro systems) stretched out across the valleys of Waipi'o, Hanalei and Ke'anae draw millions of tourists annually. Its image inspires business logos, advertising and political campaigns. Kalo plays a critical role in the recovery of families at risk, and children at promise, across the state through a myriad of school, nonprofit and social service projects and programs. Yet, all of this is at risk. Taro cultivation is under threat of collapse economically, ecologically and culturally due, in large part, to the apple snail, *Pomacea canaliculata*.

This apple snail, often called Golden Snails for the economic boon they were supposed to bring growers, is listed as one of the worst 100 Global Invasive Species and is an established noxious pest in Hawai'i. It is considered a high priority aquatic invasive by the Division of Aquatic Resources. While it is currently illegal to bring the snail into Hawai'i or to transport live snails between islands, it is still legal to sell live or processed snails from local sources.

This snail was first brought to the Hawaiian Islands by the aquatic pet trade in the late 1970's. Introduction to taro farms in the early 1980's took another route, most likely direct from the Philippines. By 1992, apple snails had spread to all the main islands, except Kaho'olawe and Moloka'i, which remain free of this pest. Deliberate or accidental introduction by humans has been the primary avenue of dispersal between islands, ahupua'a, and isolated fresh water sources. Once the snail arrives in a watershed, downhill dispersal can occur under the snails own power. Perennial wetlands, at the bottom of a freshwater systems provide ideal habitat for growth, and are the most difficult to address for control efforts.

In the last 20 years, Pomacea canaliculata has shifted from an agricultural pest to a serious threat to wetlands across the state. New assessments indicate almost 11,000 acres of wetlands, ponds, lower stream reaches, springs, taro growing systems and other habitat are at risk or already invaded by this snail; of which only 5% are taro farms and 95% are private, public, state and federally managed wetland ecosystems important to the health of Hawaii's endangered freshwater bird populations and nearshore reefs.

Despite the snail's status, over the last 16 years only an estimated $380,000 have been applied to control of this species in Hawai'i, with the result being a dramatic increase in its distribution and population size.

This species of apple snail has an almost indestructible nature. It can breath on land and underwater and can hibernate in the mud for months. It reaches sexual maturity at roughly 2-3 months, can live for up to 5 years, and a single snail produces from 4,300-8,700 eggs annually. It has a voracious appetite for a wide variety of aquatic plants, including watercress, however, because its preferred habitat is lo'i kalo and wetlands in Hawai'i, it is kalo that suffers most.

More than half of all taro lands are infested with the apple snail. Crop loss is estimated at 18-25% annually and efforts to control the pest have increased labor, time, and cash *inputs collectively by as much as 50% above traditional production costs. Farmers lose an average 32 work days annually due to snail related injury. Families who depend on growing kalo for home consumption are at risk of increasing food budget needs by an average 64% without access to this traditional food source.*

In 2004, 'Onipa'a Nā Hui Kalo, a statewide hui of taro farmers, initiated an economic impact study of the snails with the University of Hawai'i. In that same year, they brought their concerns to the Coordinating Group on Alien Pest Species. The Department of Land and Natural Resources, Division of Aquatic Resources funded the development of a statewide, strategic control plan for *Pomacea canaliculata* in May, 2005, the details of which are found in this document, the *Statewide Strategic Control Plan for Apple Snail (Pomacea canaliculata) in Hawai'i.*

The Plan gathers into one place the most relevant information about the ecology and behavior of the snail; it maps out currently known distribution; assesses environmental, agricultural, health, educational and cultural impacts; and a wide variety of control measures which have been applied over the past 20 years with varying degrees of success by the Hawai'i Department of Agriculture and taro farmers themselves (Sections 3 through 6).

The snail does not appear to have a biological Achille's heel, yet, except to starve it of water. The often recommended control method, hand-picking, is unsustainable back-breaking work. However, in combinations with long-term fallow (2-3 years), trenching, screens, domestic ducks, cover crops, and attention to seasonal snail cycles, successful reduction of snail populations, and even eradication, have been reached. There is some evidence that a controversial pest-for-profit program may have precipitated further introductions of the snail to previously uninfested sites and perpetuated other populations by creating a need for a continual source. There is a critical need for outreach education within the Filippino community about the impacts of this pest and the disease risks associated with its consumption.

To date, no systematic, strategic, ecologically, or economically sound approach has been applied to control of this species at a landscape level. No state or federally managed wetland has implemented apple snail control measures with the exception of one brackish water site. These habitats continually re-infest taro farms in the surrounding landscape during heavy rains and floods.

Sections 7 through 9 provide recommendations for a number of stakeholders affected by this pest, from individual taro farmers to wetland managers, invasive species control groups, agencies, legislators, educators, nonprofits, businesses and the general public. It provides guidance on the best directions for both on-farm and landscape level control efforts and key actions for a few specific sites. It addresses the need for changes in law, rules and policies and estimates the funding necessary for the next 10 years to correct the unchecked growth of this invasive species over the last 20 years (Section 9). Perhaps most important, this document describes the key partners (Section 8) and their recommended roles for success in reducing and eradicating *Pomacea canaliculata*, protecting snail-free places and preserving the benefits and cultural traditions of taro in Hawai'i.

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Agency acronyms

ACOE — Army Corps of Engineers
CGAPS — Coordinating group on alien pest species
DHHL — Department of Hawaiian Home Lands
DLNR — Department of land and natural resources
- DAR — Division of aquatic resources
- DOFAW — Division of forestry and wildlife

DOH — Department of health
- CWB — Clean water branch
- DOCD — Disease outbreak control division

DOT — Department of Transportation
EPA — Environmental protection agency
HDOA — Hawai`i department of agriculture
HISC — Hawai`i invasive species council
- ISC — Invasive species committee (one on each island)

ISSG — Invasive Species Specialists Group, IUCN
MEO — Maui Economic Opportunity (business development program)
NRCS — Natural Resources Conservation Service, USDA
OHA — Office of Hawaiian affairs
QLCC — Queen lili'uokalani children's center
SARE — Sustainable Agriculture Research and Education program, USDA
UH — University of hawai'i
- CTAHR — College of tropical agriculture and human resources
- SEA GRANT — A research institute of the ocean and earth science and technology school

USDA — United states department of agriculture
- NRCS — Natural resources conservation service

USFWS — United states fish and wildlife service

1. Intent

The *purpose* of this document is to provide **a clear plan of action** for **strategic control** of *Pomacea canaliculata* (apple snail), and only this species, in the taro growing lands and wetlands of the state; **prevention** for areas that currently do not have apple snails; **protection** of the rich biodiversity of traditional Hawaiian taro varieties; and **preservation** of a culturally important and unique way of life, all of which have been placed at high risk because of this pest. The purpose is also to clearly identify necessary individual, agency and policy/legislative actions, research, timeframes, partners, and funding. The plan recognizes varying levels of experience and awareness regarding the snail and taro farming. The document will help farmers, organizations, and agencies provide a consistent, clear message and a strategic, coordinated approach to apple snail control.

The *intent* of the plan is not to create a document that sits on a shelf and gathers dust, but rather, one that vibrates and rumbles and calls forth real action from every possible individual, agency and organization that has the potential to contribute to reducing the apple snail population and perpetuating taro farming in Hawai'i.

For those of you who remember Lake Wilson in 2003,[1] apple snails are the *Salvinia* of the agricultural community and the Hawaiian community. Taro farming is on the brink of disaster. And, while lo'i kalo (wetland taro systems) represent less than one percent of agricultural lands in the state, it is *the* most important cultural crop in Hawai'i. If we lose the ability to grow taro, we lose far more than a food or cash crop; we lose the cord that connects Hawaiians to their past, the future, and to each other. It is not enough for any of us to "study the problem further" or "think about it" any longer.

It is with *intent* that this document was developed from the ground up by those who have been most directly impacted by the snail, who have been the keenest observers of the snail's cycles and behaviors, and who know the realities of taro farming and what is truly feasible.

If you have received a copy of this plan, it is with *intent*. You have been asked, by accepting this document, to become part of the solution *in a concrete and measurable way*.

You will find your role and a timeframe for the requested action (whether you are a legislator, agency, organization, researcher, business person, taro farmer, or member of the general public) listed in the following Sections: Recommendations and Resource Needs. A member of 'Onipa'a Nā Hui Kalo will follow up with you to encourage coordinated efforts, and to track implementation and results.

E ku'i ka māmā a loa'a 'o Ka'ohele.
Let your fastest runners run in relay to catch Ka'ohele.
Let us make every effort to attain our goal.

[1] The *Salvinia* problem in Lake Wilson began a number of years prior to 2003, but it was that year when this aquatic weed, and invasive species in general, got the attention of the governor, and the entire state.

2. Background

Taro farmers began to plead their case for the eradication of *Pomacea canaliculata*, the focus of this Plan, several years after its introduction into taro patches somewhere around 1983-84. On Maui and Kaua'i, two key taro farming districts were hit hard. Individual communities tried to find solutions to the problem, with assistance from the County of Maui, Hawai'i Department of Agriculture (HDOA), University of Hawai'i SEA GRANT and other agencies, but found little success. A limited amount of resources have been applied to the issue for the last 17 years, with the result being a dramatic increase in the distribution and population of the snail. By 2003, the snails had become such a widespread problem that farmers throughout the state began to feel it was far beyond their control and that the survival of their crop and their way of life was in jeopardy.

In late 2004, 'Onipa'a Nā Hui Kalo, a statewide hui of taro farmers, initiated an economic impact study of the snails to taro farming in collaboration with the University of Hawai'i, College of Tropical Agriculture and Human Resources (CTAHR) and the UH Center for Conservation Research and Training (CCRT), in an effort to quantify snail damage as the basis for demonstrating the importance of controlling this aggressive invasive. In that same year, the Hui brought their concerns to the Coordinating Group on Alien Pest Species (CGAPS). General discussions began with a variety of state agencies and communities regarding the magnitude of the apple snail invasion, past control efforts, farmer experiences, and the need for serious action.

In January 2005, 'Onipa'a Na Hui Kalo members from each island, duck specialists, and representatives from policy setting/decision-making agencies, including HDOA, Department of Land and Natural Resources Division of Forestry and Wildlife (DLNR-DOFAW), the University of Hawai'i at Mānoa and Hilo (UH), and US Fish and Wildlife Service (USFWS) met for a day at the Queen Lili'uokalani Children's Center (QLCC) for a roundtable discussion regarding duck issues and apple snail control.[2] These agencies worked with taro farmers to help develop guidelines for using ducks as a control mechanism, as one piece of a comprehensive pest control strategy.

In May 2005, the DLNR - Division of Aquatic Resources (DAR) generously provided funding to assist in the development of a statewide, strategic control plan for *Pomacea canaliculata*, the results of which are found in this document, *Statewide Strategic Control Plan for Apple Snail (Pomacea canaliculata) in Hawai'i.*

From June 2005 through March 2006, I met and talked with taro farmers on-farm, by phone, email, in groups, attended meetings and taro festivals on each of the main islands as farmers furthered their discussions, focused on and shared their experiences in controlling the snail, and refined best management practices and directions for strategic, statewide control efforts. I also queried and interviewed many people from a number of agencies, including the HDOA, Department of Health (DOH), DOFAW, DAR, and UH.

[2] The roundtable was made possible by a grant from the Hawai`i Community Foundation (HCF).

Along the way, CGAPS, the Hawai'i Invasive Species Council (HISC) outreach groups and individual Invasive Species Committees (ISC) on each island have been strongly supportive of making the apple snail issue more visible and continue to assist in outreach education.

Farmers recommended that the Plan provide clear guidance on who, what, where, when and how to focus individual and organizational efforts to best affect, including necessary legislation, funding strategies, further studies, controls research, on farm and ahupua'a-based practices,[3] special issues for wetlands, education and outreach. They very clearly want to close the gaps in policies that allow such an aggressive pest to be raised and marketed at the expense of so many. What is contained in this Plan is realistic and holistic because of their efforts. That does not, however, mean that achieving the primary objective of this plan to significantly reduce apple snail populations statewide will be easy.

Most importantly, this document has been developed from the ground up. Those who have the most to lose – taro farmers - have been the lead, with the support of collaborating agencies. We hope this will create a broad level of cooperation for future action.

He pūko'a kani 'āina.
A coral reef that grows into an island.

[3] An ahupua'a is a traditional Hawaiian district whose boundaries frequently followed ridge lines on either side of a stream or valley and encompassed the highest mountain peak and the reef at the coastline.

2.1 STAKEHOLDERS

If kalo were to be lost to apple snails, it is obvious that the most immediate stakeholders would be taro farmers[4], but the net of stakeholders is much wider. The list is long, and perhaps, somewhat surprising to those who haven't pondered the role that taro plays in their lives, or imagined that their lives or the core of the State's economy, are connected to kalo in any way.

Immediately connected to taro farmers are their family members, and their extended family and friends who benefit from the food produced in the lo'i. There are 20 permitted poi millers in the state (Department of Health 2005); some family run and others employing outside workers. Together they produced 3.9 million pounds of poi last year, which at one estimate could contribute to upwards of 15.6 million meals (at 4 servings/lb) on tables in Hawai'i (Levin et al. 2005).

There are no numbers yet for the "value-added" businesses who use kalo to produce flour, lavosh, bread, pie, and chips annually. Restaurants across the state used kalo in salads, main dishes, and desserts. Tourists try poi at countless lū'au on every island. If you attended a baby lū'au, wedding, or graduation party, it's likely at least one of those events served poi, lū'au (with squid if you were lucky), or cooked taro.

Every tourist who took a ride to the end of the road to see the view overlooking Hanalei, Kaua'i; Ke'anae, Maui; or Waipi'o on Hawai'i gazed over the beauty of a glistening network of lo'i kalo – and took plenty of pictures to show relatives and friends, perhaps influencing others to visit here. These "billion-dollar views" have graced the pages of travel brochures and guide books, coffee table books, the covers of real estate magazines and contributed substantially to the marketing of Hawai'i to the rest of the world.

The image of the taro plant has been incorporated into a myriad of successful ad campaigns, building designs and logos, including the prominent conversion of the American Savings Bank (the fees earned by consultants and designers from kalo's image annually, along with many of the above mentioned values are unrecorded in economic analysis of the value of kalo to the state). It has provided inspiration to innumerable artists, videographers, writers, chanters and dancers, of all ages.

Kalo is an unpaid teacher in all your schools in curriculum on Hawaiian history and culture from grade school to college. Thousands of students and teachers visit local taro farms annually. If your child is lucky enough to attend a school with a strong Hawaiian culture component, a charter school, or a Hawaiian immersion school, a lo'i kalo features strongly in all aspects of their learning along with providing food for special events at the school. At the University of Hawai'i at Mānoa, entire courses are taught in the lo'i; several researchers have made their careers on various aspects of taro and the taro industry.

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[4] There is no data available on the number of taro growers in Hawai'i currently. 'Onipa'a Nā Hui Kalo, a statewide organization of taro farmers has an estimated 300 members, inclusive of full and part-time farmers, cultural practitioners, and others interested in learning about or participating in growing kalo. Backyard growers are a completely unaccounted for group.

Our elders are cared for by the healthful properties of poi and lū'au; hospitals use poi as an important food for burn patients and those with digestive disorders, especially the very young. For those with wheat allergies, taro is a life-saving alternative. Kalo is a crucial food for Hawaiians fighting to change the statistics of obesity, diabetes and heart disease.[5]

Kalo is the genealogical elder brother for an estimated 258,490 Hawaiians or part-Hawaiians living in the Islands, and another 142,672 more scattered to the mainland (Hawaii Data Book 2004). It represents more than 1,200 years of Hawaiian cultural and agricultural history. For today's cultural practitioners, specific taro varieties play an active role in ceremonies, food, medicine and even bait for fishing, just as they did in the past.

That accounts for almost everyone in Hawai'i; and then there are the "non-human" stakeholders.

Lo'i kalo systems play an important role in environmental health. They support important endemic and endangered freshwater fauna, including native dragonflies and damselflies, 'o'opu (native fish), koloa (Hawaiian duck, *Anas wyvilliana*), 'alae ke'oke'o (Hawaiian coot, *Fulica alai*), 'alae 'ula (Hawaiian gallinule, *Gallinula chloropus sandvicensis*), ae'o (black-necked stilt, *Himantopus mexicanus knudseni*) and the indigenous 'auku'u (black-crowned night heron, *Nycticorax nycticorax hoactli*). Where lo'i kalo are active, they keep invasive plants from consuming wetland acreage and keep water returning to streams, which in turn, feed nearshore fisheries and reefs. The presence of taro farmers on the land provides active protection and improvement of watersheds, wetlands, coastal waters, and cultural sites.

[5] The *Hawaiian Data Book* 2006 (OHA 2006) reports an estimated 87,432 Hawaiians overweight or obese in 2002; 85.6 individuals out of every 1,000 at risk for high cholesterol; 46.5 per 1,000 for diabetes; 178 per 1,000 for high blood pressure; and 111 per 1,000 for hypertension.

2.2 History of known snail control efforts and related events in hawai`i

1970's	The Hawaii Department of Agriculture (HDOA) allows the importation of apple snails (inclusive of *Pomacea canaliculata*) for the aquatic pet industry beginning in the late 1970's.[6]
@1983-84	*Pomacea canaliculata* **arrives** in taro patches in **Maui** (Ke'anae).[7]
@1987	*P. canaliculata* **arrives** in taro patches in **Kaua`i** (Waipā).
1989	*P. canaliculata* documented and **confirmed** by scientific identification as present in **Maui**.[8]
	County and state agencies meet with taro farmers to assess the apple snail problem in Ke'anae and Wailua nui, Maui and try to find solutions.
	HDOA allows use of *P. canaliculata* in the state for the development of an escargot industry in an attempt to find a use for the pest.
	Maui Economics Opportunity (MEO) sponsored apple snail projects initiated.
1990	Apple snails **arrive** in taro patches on **O'ahu**. Copper sulfate trials initiated on Maui.
1992	Distribution survey conducted. Apple snails **confirmed** on **Kaua'i, O'ahu, Hawai'i** (Waipi'o) and Moloka'i (*Pila conica* only). Copper sulfate trials initiated on Kaua'i. Solarization briefly tested as a control technique.

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[6] In hindsight, HDOA recognized the mistake in allowing the initial imports (L. Wong, HDOA, pers. com. 2006)

[7] It is important to note that the first arrivals of apple snails in lo'i kalo do not appear to have a strong link to escapees from the aquarium trade when one considers the likelihood that a "snail pet owner" would go so far out of their way as to dump a "pet" into the rural streams that feed the primary taro systems in the state, rather than into an urban channel, storm drain or sewer system.

According to available documentation, *Pomacea canaliculata* was not introduced to Asian until about 1979-80. Mitochondrial DNA studies by Ken Hayes and Robert Cowie (UH CCRT) indicate that samples pulled from taro patches in Hawai'i are a single genetic form identical to those from the Philippines; not Brazil (R. Cowie and K. Hayes, pers. com. 2006). In addition, taro farmers at a number of sites can pinpoint the source of introduction with a high degree of accuracy. To date, none have been correlated with the aquatic pet industry. At least one case appears to have come directly from the Philippines. Many others have been associated with local Filippino farmers establishing an accessible food source (a similar native snail is eaten in the Philippines).

[8] Taro farmers on Maui document the presence of apple snails as early as 1983-1984. In 2004-5 interviews, several Maui farmers indicated they had been "dealing with the snail" for "at least 20 years" [1985], indicating the snail had arrived somewhat earlier, with time to build up a large enough population to be a nuisance to taro growers. For a new organism to come to the attention of scientists for identification, it is likely to have already established at least an incipient-level population before it is noticed and brought in for identification. The apple snail case illustrates two weak links in the effectiveness of rapid response teams for newly arrived alien species in the last 30 years; delayed awareness and reporting from the community side and delayed response from agencies.

1993 Mesh bags introduced as a snail capture method at water intakes (wind sock).

Demonstration duck control projects tested on Maui; a farmer designed vacuum for sucking up larger snails was also tested.

1994 Educational flyer produced and distributed in Ilocano and English with a focus on the Filipino community.

Full color flyer with pest alert for apple snail produced and distributed in English with a focus on the general public.

Pacific Island Farm Manual produced a farmer information sheet on apple snail identification and control methods.

Muriate of potash briefly tested as a snail control compound.

EPA issues a temporary registration and use permit under a Special Local Need Registration (SLN) label for copper sulfate for two years. Label indicates use is strictly defined and regulated.

1995 House concurrent resolution considered language to ban apple snails but the resolution did not make it out of committee. The legislature instead supported funding a "pest-for-profit" program for snail control.

Integrated pest management taro-snail production projects initiated (pest-for profit program) jointly with taro farmers, Boki Farms (the only captive breeding apple snail facility in the islands at the time), UH SEAGRANT and HDOA.

HDOA provides detailed copper sulfate training to famers in Hanalei, Kaua'i. An entomologist is sent to Central America (Brazil) to search for biological control agents for the snail. Nothing promising is found.

Apple snails deliberately dumped at several locations in Ke'e, Kaua'i[9], including **Limahuli**; their presence is **confirmed** on **Lana'i**.

1996 Chemo-attractive bait studies were pursued with mainland researchers; initial results suggested that a general or species specific bait might be possible to develop.[10]

Apple snails deliberately dumped in **Hanalei Refuge**, Kaua'i.

1996 cont'd Copper sulfate use permit terminated; it is no longer an allowable chemical for use in taro patches as a snail control.

1998 Limited comparative study of ducks and hand picking methods conducted.

Distribution survey of *Pomacea canaliculata* completed on O'ahu.

2001-2004 Hawaii Agricultural Research Center (HARC) researches papaya and neem extracts, and ferric phosphate (a molluscicide) for apple snail control.

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[9] Documented in the *Kaua'i Times*, 13 December 1995.

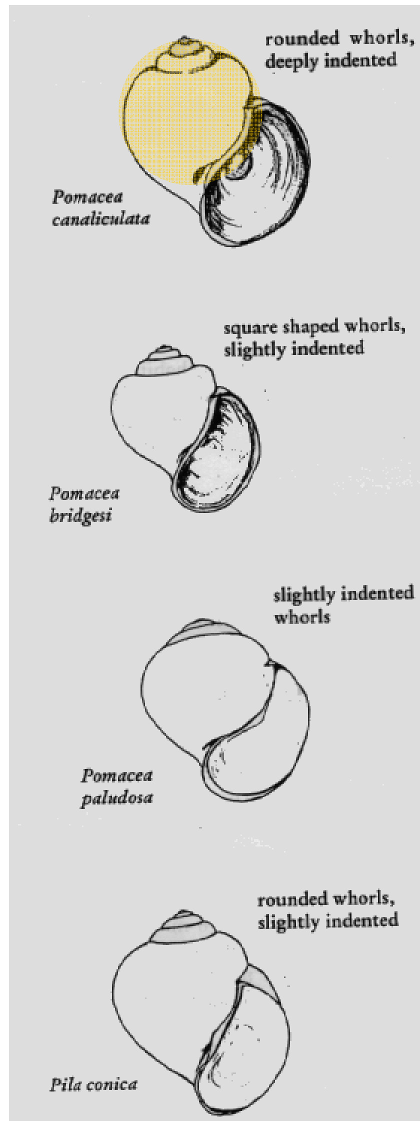
[10] The study stopped when funding ran out.

2003	'Onipa'a Nā Hui Kalo begins concerted efforts to find statewide support for apple snail control and educate farmers and agencies.
	State of Hawai'i Aquatic Invasive Species Management Plan completed. The plan identifies the apple snail *Pomacea canaliculata* as a species of concern case study
2004	*Economic Impact of Apple Snails on Taro Culture in Hawai'i* study initiated.
2004-2006	Statewide snail distribution field survey and mapping conducted.
2005	HARC initiates research into mugwort and yucca compounds as snail control.
	Development of a statewide strategic control plan for apple snails in Hawai'i initiated.
2006	*Economic Impact of Apple Snails on Taro Culture in Hawai'i* study completed. The results of the study inform the statewide control plan.
	Kaua'i Invasive Species Committee (KISC) features apple snails in its first issue of the newsletter *Kia'i Moku: Guarding the Island*.
	Statewide Strategic Control Plan for Apple Snails (Pomacea canaliculata) in Hawai'i completed. Discussions of next steps begin with CGAPS and various state and federal agencies.
	Taro Festivals provide venue for outreach education about apple snails on Maui and Kaua'i.

3. Snail ecology

The apple snail *Pomacea canaliculata* has been recognized internationally as one of the top 100 Global Invasive Alien Species (IUCN Invasive Species Specialist Group; www.issg.org/database). First introduced to Asia around 1980, over the past 25 years it has been clearly documented as a major pest in 18 countries worldwide, including the United States. In 2002, representatives from the U.S. State Department attended a Global Invasive Species Programme Conference in Thailand that focused on apple snails. In that same year, it issued a national alert for the species.

Apple snails are known by a number of other names locally, including 'mystery snail', 'golden snail', 'golden apple snail', 'kuhol' in the Philippines and 'bisocol' by the Filipino community in Hawai'i (Cowie 2002), a name given to *native species of apple snails* in that country.



Source: ADAP 1995

Apple snails are not native to Hawai'i. Four species of Ampullariidea (the scientific name of the family to which apple snails belong) have been recorded in the Islands: *Pomacea bridgesii* and *Pila conica*, both present since the 1960's, *Pomacea canaliculata* arriving in the 1980's and *Pomacea paludosa* around 1990 (Cowie, 1995).

It is *Pomacea canaliculata* that has become a serious threat to taro and watercress farmers, and wetlands throughout the state.[11] This is the species referred to in the remainder of this Plan.

The most complete summary of the biology of *Pomacea canaliculata*, and apple snails in general is found in the paper "Apple Snails (Ampullariidae) as Agricultural Pests: their Biology, Impacts and Management" (Cowie, 2002), the biological portions of the text of which can be found in Appendix A. Below, the key characteristics and behaviors of the apple snail are outlined to improve invasive species control coordination by both farmers and agencies. The information (along with its introduction history) reveals why this pest represents such a challenge to standard approaches for alien species control in Hawai'i.

[11] While *Pomacea canaliculata* has not reached all islands or all wetlands in the state, they are "at risk" statewide.

Physical characteristics

- Shell color ranges from a "golden" yellow to muddy greenish-brown to almost black. Shell color is not a distinguishing feature for differentiating *Pomacea canaliculata* from other species of apple snails. Shell shape and egg color is. The diagram on the previous page demonstrates the structural differences between the four Ampullariids found in Hawai'i, and the difficulty in telling them apart.

- The eggs of *Pomacea canaliculata* are bright pink. Those of *P. bridgesi* and *P. paludosa* are more orange in color. *Pila conica* eggs are whitish and are distinguished by being found in hollows and depressions on the surface of the mud rather than on vegetation as with the three *Pomacea* species.

- The operculum (a plate, like a trap door, that seals the animal in its shell) for *Pomacea canaliculata* is of a horny texture. This plate can be sealed so tightly that nothing penetrates, allowing snails to withstand immersion in a variety of substances and remain deep in the mud for long periods of time without harm.[12] This has significant ramifications for the success or failure of chemical control mechanisms.

- Snails can reach baseball size over time,[13] but adult snails more often range from the size of a macadamia nut to a lime in Hawai'i. Female snails have been reported in some studies to be larger than males, but it is not apparent in the field in Hawai'i (Cowie 2002). Some researchers report being able to distinguish between male and female in *Pomacea canaliculata* by the concave shape of the operculum (female) and a convex lip on the outer edge of the operculum (male) (SARE 2004), but this is unconfirmed as a determining feature.

- Snail maturity in Hawai'i has been estimated at 3 to 4 months; possibly influenced by seasonal temperatures (Cowie 2002).

- Immediately after hatching, snails are hardest to detect because of their small size and translucency. This is the stage most likely to be transported on huli (taro propagules). Immediately after hatching, they travel from the egg mass on a stem, down the plant to the water and are easily hidden between leaf axils or at the base of the plant.

- A structure within the mouth of *Pomacea canaliculata* makes rasp-like cuts on a plant as it eats; plant damage is rapid and consumption is often complete. Damaged plants are more susceptible to disease. In taro patches with substantial, uncontrolled snail populations, an entire crop (from corm to leaf tip) can be consumed within a few days time. Young taro plants are highly vulnerable to even minimal populations of this pest.[14]

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[12] Cowie (2004, pers. com.) reports having to puncture *P. canaliculata* shells in order to preserve specimens, without which the preserving solution does not reach the interior of the shell and the organism rots.

[13] Snails of this size found by a farmer on Maui were provided to Cowie, Hayes and Levin during field survey in December 2004.

[14] Farmers regularly replace huli after complete consumption by apple snails within the first few weeks of planting, even where snail populations in a patch have been suppressed.

- Apple snails are amphibious; being equipped with a modified pulmonary sack (a sort of lung) and a gill allowing them to breathe above and below the water (Cowie 2002). Snails are observed to float to the water surface and breathe air where waters are polluted, lack oxygen or contain what might be considered an "unpalatable" substance.

- Apple snails will bury in the mud during induced or natural drought periods. Farmers also observe rapid burrowing and "flight" even in water, in response to disturbance in the lo'i. Snails aestivate (a state of dormancy similar to hibernation) in mud. *Pomacea canaliculata* is reported to survive only up to 3 months below soil surfaces (Cowie 2002); however, a strong cautionary is advised. Mochida (1991) supports survival longer than seven months (Cowie 2000). A number of farmers report 4-12 month fallows only reduce snail populations but do not eliminate them.

  At least five farmers have reported recurrent infestations after fallows of 1 year or more; two in areas that were completely isolated and with clean stream sources. Only after increasing fallow length to 2.5 to 3 years were snails completely eliminated. Survival may be related to snail age, with youngest (smallest) snails dying off more rapidly than older (larger) ones. It may also be related to the geological conditions of Hawaii's soils. Underground springs and water flows permeate the islands. Snails may survive longer during aestivation where these underground water sources exist.[15]

- This pest has a ring of ganglia (a concentration of nerve cells) centralized in the head region around the esophagus that functions as a nervous system. Despite the presence of a nervous system, the snail can tolerate high levels of electrical shock. Stun gun technology sometimes used to clear invasive aquatic species from streams was tested on apple snails and found to have no permanent effect. Snails in tubs began to recover after a couple of minutes from high level shocks (S. Hau, 2004).

Reproduction

- Apple snails are dioecious (separately male or female) with what appears to be an almost 1:1 ratio of males to females in the field (Cowie 2002). *Pomacea canaliculata* mates several times per week day or night.

- They are internally fertilizing and oviparous (producing eggs that hatch outside the body) (Ibid). Eggs may be laid anywhere from 24 hours to 2 weeks after mating. Clutches are laid as frequently as every 5 days to every 2 weeks with varying numbers of eggs per clutch and hatch in Hawai'`i within 2 and 3 weeks.

- Clutch size for *Pomacea canaliculata* averages roughly 200 eggs, with some estimates as high as 1,200. A range of 4,375 to 8,680 eggs per year has been recorded (Ibid). An

[15] This is suggested by farmers who observe that at sites where underground water sources (springs, streams and chambers) are known to exist, snails took almost three years to eradicate using fallow. This suggests significant changes need to be made in recommendations for fallow length. It also suggests a dimension of spread that has not been part of the equation before (duration of underground survival) and perhaps the existence of below ground active populations.

estimate of about 22 clutches per year has been given. Reproductive rates are probably sensitive to temperature; Hawai'i appears to be an ideal habitat in this regard.

- Some seasonality may be observed in egg laying of *Pomacea canaliculata* in Hawai'i, with highest rates occurring in warmer months from March to August; however reproduction and egg laying occurs, to some degree, year round here.

- Egg clusters are deposited on the stems of plants and other objects protruding from the water surface. The clusters are dark pink when first laid, turning a lighter pink as they dry, and are easily visible. Eggs are individually cased in a calcium carbonate shell which may have some bitter or toxic qualities (Ibid).

- Eggs of *Pomacea canaliculata* do not appear to tolerate being submerged in water.

- Some studies record that apple snails appear to breed and produce eggs most intensely at lower population densities (Kenji 2004). This may have significant ramifications for the degree to which snail populations must be reduced in lo'i kalo in order to push populations into real decline.

Habitat

- Taro patches, ponds, ditches, springs, marshes, wetlands, estuaries, and other similar water bodies are favored. Lo'i kalo appear to be the most common habitat in Hawai'i. Cowie (2002; p148) suggests that "some species [of apple snail] could be considered pre-adapted for living in rice paddies, taro, and other similar aquatic habitats in which agricultural crops grow."

- Apple snails live in slow moving or stagnant freshwater with warmer temperatures and even thrive in polluted waters. Mortality in *Pomacea canaliculata* is high in waters above 32 to 35 degrees Centigrade (89.6 to 95 degrees Fahrenheit) (Cowie 2002, Lach and Cowie 1999).

- Snails do not tolerate extremely cold temperatures; however studies report survival of 15 to 20 days at 0 degrees Centigrade declining sharply to a few hours at -6 degrees (32 and 21 degrees F. respectively). Sexual maturity and egg production slows significantly at lower temperatures (Ibid). Where lo'i kalo had access to cooler water sources, egg clusters did not show up for 6 months or more after initial infestations.

- This pest can tolerate low levels of salinity. Cowie (2002; p161) writes that "preliminary observations suggest that *P. canaliculata* is sufficiently tolerant [of ocean water] to be carried by current from one stream mouth to another [in Hawai'i], thereby providing the expansion of its distribution." Tests conducted by taro farmers have shown the snail able to survive longer than 24 hours in ocean water.[16] Hau suggests that muddy interface between stream mouths and the ocean may provide enough freshwater for survival, dependent on the degree of salinity (S. Hau, pers. com. 2006). This has significant implications for snails washed by flooding into coastal waters where tides may move them further up or down the shoreline or potentially from one bay to the next.

- Faster, colder waters do not favor apple snail establishment and may be unsuitable for *Pomacea canaliculata* establishement (Lach and Cowie, 1999). Severely diminished stream flows (volume) throughout Hawai'i, and their subsequent impact on the availability of cooler water flows to lo'i kalo have a probable relationship to the presence of magnified apple snail populations in most taro growing areas.[17]

- Snails appear to prefer shallow waters (1 foot or less) in Hawai'i; where water depths reached 3 feet or more in marshy areas *with little or no vegetation*, relatively few snails are observed in Hawai'i. In their native Brazil, *Pomacea canaliculata* prefers deeper waters and are found from 1 to 5.6 feet. Where dense vegetation grows above the waterline in Hawai'i, snails and egg clusters are found in deeper water living in the vegetation but do not appear to be found on the muddy bottom (Levin, field notes 2004).[18]

- The snail can tolerate significant amounts of time out of the water.

- Hanalei, Hawai'i appears to have some of the highest population densities of *Pomacea canaliculata* per square meter in the world, at 130 m^2 (approximately 12 per square foot). One 30 acre farm in the valley was reported to have an estimated range of between 1.7 and 6.8 million snails of greater than 0.5 grams body weight (Tamaru, Ako and Tamaru, 2004).[19]

Behavior

- In Hawai'i, snails feed extensively on taro even where other weedy plants are available for consumption. They have also attacked watercress farms and eat other wetland vegetation indiscriminately. In tanks they have been known to cannibalize each other where no other food is available (N. Matayoshi, pers. com. 2005). This suggests potential mitigating strategies for lo'i kalo in densely populated situations could possibly involve removing all food sources to encourage self-depredation.

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16 F. and N. Reppun in Cowie 2002. At least three apple snail sites found during 2004-2006 survey were located in the brackish interface between a stream and the ocean in bays with limited wave action (*Pila conica* on Moloka'i, and *Pomacea canaliculata* at two O'ahu sites).

17 Based on previously cited documentation in this Plan which suggests that apple snails favor warmer water in habitat selection, mature more rapidly and produce more frequent egg clusters in warmer seasons and habitats.

18 These populations may or may not float in from upstream. Hau bush (*Hibiscus tiliaceus*) and California grass (*Brachiaria mutica*) masses in wetlands are often found with apple snails or egg clusters inhabiting them.

19 These numbers did not take into account an almost equal number of snails smaller than 0.5 grams or those under the mud.

- *Pomacea canaliculata* appears to be able to detect food at some distance using chemical cues in the water (Cowie 2002). This suggests the effectiveness of toxic baits and compounds may be related to their ability to override the snails' alarm response; chemical masking of these compounds may be needed.
- Snails live and feed primarily below the water and lay eggs above the water line.

- Farmers observe that snails are continually active but more so from dusk to dawn. This is particularly true for egg laying (Cowie 2002).

- They are able to move across grassed berms between lo'i, especially during the rainy season and at night.

- Apple snails can float (by closing and sealing the operculum) allowing them to move rapidly in flowing water. This is readily observed between taro patches and along 'auwai where snails close up and roll with moving water as fast and as far as it will take them, or until they reach the next browsing site. In shallow water, they move relatively quickly propelled by movement of the "foot". The question of whether the snails move upstream in Hawai'i is unconfirmed at this time. Cowie's early survey work on O'ahu documents snails present at Waikāne bridge at Kamehameha Highway in 1992. In 1998 they were found 100 meters upstream and 300 meters downstream. In Japan, *Pomacea canaliculata* has been documented moving an average of 328 feet upstream and 1,640 feet downstream per week in canals (Kenji 2004). This suggests that lower stream reaches with slow moving or low flow water above lo'i kalo in infested ahupua'a may be at higher risk than previously considered.

- Snail reproduction and movement slows during winter months (colder temperatures, overcast skies and rain). Population "blooms" begin in March and peak from mid- to late summer in Hawai'i.

- During cold periods, or when under threat, apple snails bury in the mud to varying depths and remain in a slowed hibernation-type state for many months. Farmers observe through deep tillage that snails can burrow to depths of 2 feet or more. The survival capacity of *Pomacea canaliculata* during such periods is not fully understood in Hawai'i. While it is likely that smaller snails die off relatively quickly, larger adults may survive much longer.

- *Pomacea canaliculata* eats a range of succulent weeds, but none to the degree that it consumes taro in Hawai'i. The snail is efficient at controlling grass in brackish water ponds but all evidence points to continued decline in habitat once grass is gone (N. Nishek 2003; Carlsson et al. 2004; Kenji 2004). It has been observed to feed on decomposing material of all types, including dead fish in drainage ditches in Kahului.

4. Apple snail distribution in the state

The apple snail species *Pomacea bridgesii* and *Pila conica* were first recorded in Hawai'i in 1962 and 1966 respectively. *Pomacea canaliculata* was officially documented as present by 1989, with one additional species, *Pomacea paludosa*, present by 1990.

Both *Pomacea paludosa* and *Pomacea bridgesii* have minor populations in the state. *P. paludosa* has only been found at one site on Maui. *P. bridgesii* has been found in small numbers at one site each on Kaua'i, O'ahu and Hawai'i. *Pila conica* is the only species of apple snail recorded from the island of Moloka'i, where it is widespread, primarily in lo'i kalo; it has also been recorded from the islands of O'ahu and Maui. *Pomacea canaliculata* is present on Kaua'i, O'ahu, Lana'i, Maui and Hawai'i in large numbers and at numerous locations (Cowie, 1995, 1996; Lach & Cowie, 1999; Levin et al 2005). Field survey using GIS technology further mapped the presence of *Pomacea* species on six of the eight main Hawaiian Islands (Kaua'i, O'ahu, Moloka'i (*Pila conica* only), Lana'i, Maui and Hawai'i) during 2004-2006 and compared current distribution to the previously documented sites (Cowie, 1995, 1996, 1997; Lach & Cowie, 1999) and taro farmers' knowledge of the snail's distribution within taro growing areas.

When this Plan was first initiated, there was a commonly held belief that *Pomacea canaliculata* was confined primarily to taro growing wetlands and to one plant – taro. It was also assumed that of an estimated 400 acres (in 2002) [20] in commercial taro production only 50 percent were under threat from this pest.[21] Neither statement is accurate in 2006. Of the nine major taro-growing areas with known commercial farms (NASS records 110 farms statewide),[22] at least seven have been recorded as hosting *P. canaliculata*.

Potential apple snail habitat

Presence/absence maps were developed for this Plan from field survey conducted on all main islands, except Kaho'olawe and Ni'ihau in 2004-2006 by Cowie, Hayes and Levin as part of an economic impact study on apples snails (USDA T-STAR grant to Cowie and Levin).[23] The maps indicate a stream or wetland where snail or eggs were present; however, given the limited scope of the survey, an estimate of acreage infested by apple snails is not possible. The maps are useful, however, in documenting the overall distribution of *Pomacea canaliculata* through the islands (see pages 35 through 39). Current forecasting models from this project can only predict locations where snails might be found and not total area.

[20] Taro acreage has steadily declined since 2000. In that year, 430 acres were recorded as commercially cultivated on 185 farms. By 2005, commericial taro acreage dropped to 350 and the number of farms to 110 (NASS 2006).

[21] HDOA and taro farmers, pers. com.

[22] National Agricultural Statistics Service, Hawai'i Field Office, 2006. Commercial figures do not include Moloka'i.

[23] New snail observations were recorded with coordinates derived from GPS. Data from earlier surveys (1989 through 2000) were also included in the database by place name, but lacked GPS coordinates. Kim Burnett, Robert Cowie and Ken Hayes assisted in development of the maps for this Plan.

Potential habitat for apple snails seems relatively easy to predict if one looks at a map. It would be expected to include all taro growing areas, ponds, and wetlands. Recent field surveys expanded this list to include isolated natural and man-made ponds (such as the University of Hawai'i Quarry Pond), springs, earthen and concreted irrigation and drainage ditches (including one that passes through the main industrial sector of Kahului), culverts, and estuarine habitats.[24] Most, but not all are located on the wetter sides of each island. Unconfirmed reports of snails in slow moving water in several dry leeward locations on O'ahu and Maui are a caution for conservation managers and health officials.

One of the hardest numbers to predict is the true scope of potential acreage that is at risk. The National Agricultural Statistics Service Hawai'i Field Office reports a total of 350 acres in cultivation divided among 110 farms in 2005 (NASS January 2006).

This number does not take into account the many taro planters who grow for other purposes, including small local markets (the island of Moloka'i is not recognized in NASS statistics), family sustenance, cultural practice, as part of alternative educational centers, and lo'i kalo at schools. These other taro lands are estimated at an additional 100-150 acres. A general estimate of 500 acres for all lands in taro cultivation is suggested.

Table. 1 Commercial taro acreage by island in 2005[25]

Island	Estimated Acres	No. of Farms
Kaua'i	235	65
O'ahu and Maui[26]	75	30
Moloka'i	unavailable	unavailable
Hawai'i	40	30
Total	**350**	**110**

More difficult to calculate is the number of fallow acres in many taro growing sites that remain water-logged and unmanaged for snails. These fields tend to be in close proximity to actively cultivated lo'i and have become “snail sinks” (collection basins) for *Pomacea canaliculata*, from which reinfestations to adjacent fields frequently occur. Aerial photograph analysis would be helpful in determining lo'i acreage that has reverted to grassland. Lo'i that have been recovered by hau bush (*Hibiscus tiliaceus*) present a problem in aerial analysis.[27] Handy and Handy (1990) provide extensive descriptions of lo`i under

[24] Cowie and Hayes have confirmed apple snail presence in brackish water in at least two locations (Cowie, pers. com 2006).
[25] NASS, January 2006.
[26] The NASS does not break down statistics for these two islands separately.

[27] It was beyond the scope of this Plan to pursue an assessment of fallow lo'i.

cultivation in the early 1900s, but no estimates of acreage. The Hawai'i Agricultural Statistics Service (NASS 2000) provides an estimate of land under taro cultivation in 1948 of 1,020 acres, potentially 670 acres of which are unused (fallow) by 2005.[28]

Lo'i kalo and fallow taro lands are logically a subset of wetlands, however, state and federal agency estimates appear limited in their overlap of wetland and taro acreage. Trying to get an accurate estimate of potential apple snail habitat (wetland area) in the state or concurrence on such a number only muddies the waters further. Many older estimates cited in land use documents in Hawai'i are based on a series of maps created by the Department of the Interior in the late 1970's. Determinations of wetland acreage from these maps were based on vegetation and open water images from aerial photographs without confirmation through ground survey.[29] The EPA lists 52,000 acres of wetlands in Hawai'i (EPA 2006). A 1998 estimate suggests wetlands account for approximately 110,000 acres in the state, including low-lying coastal areas and elevated forest wetlands (Young, Harrigan and Fukunaga 1998).

The *Draft Revised Recovery Plan for Hawaiian Waterbirds* (USFWS 2005: 45) reports 110,800 acres of wetlands and deep freshwater habitats "of which 81 percent are classified as palustrine (marshy) scrub-shrub forest habitat, which are not used by Hawaii's four endangered waterbirds." Wetlands considered as prime habitat for these species in 1990 were as little as 15,474 acres (Dahl in USFWS 2005).[30] This number, however, did not include wetland taro, lotus or watercress farms. The Recovery Plan specifies actions for Core and Supporting wetlands that USFWS considered to be critical to Hawaiian waterbirds for a total of 8,691 acres (Table 2). Core wetlands were primarily ponds, refuges and fishponds; Supporting wetlands included only some taro lands, saltponds, wetlands, river bottoms, reservoirs, ponds, fishponds, sewage treatment plants, and stock ponds, but not all.

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[28] Some land may have been lost to development; however, a significant number of ancient lo'i sites are still present throughout the islands.

[29] P. Galloway, pers. com. 2006. A more recent and accepted criterion for identifying wetlands is provided by 1987 Army Corps of Engineers (ACOE) Delineation Manual. ACOE determination for a wetland must meet three criteria: a predominance of hydrophytic vegetation, hydric soils, and the presence of water saturation (inundation) for a minimum of 18.5 days out of the growing season (year-round in Hawai'i).

[30] Dahl suggests roughly 22,475 acres of wetlands would have supported waterbirds in 1778 (around the time of Captian Cook's arrival).

TABLE 2. ESTIMATED CORE AND SUPPORTING WETLAND ACRES BY ISLAND IN 2005 [31]

Island	Core Acres	Supporting Acres	Taro lands included in USFWS count
Ni'ihau	1,900	--	--
Kaua'i	1,318	1,053	209
O'ahu	1,528	1,325	--
Moloka'i	45	108	--
Lana'i	--	7	--
Maui	837	254	3.7
Hawai'i	119	197	--
Total	**5,747**	**2,944**	**211.7**
All Core and Supporting Wetland Acreage	**8,691**		

A query to the USDA Natural Resource Conservation Service soils database for "hydric soils that pond" produced an alternative dataset (C. Smith, pers. com. 2006). The total acreage of soils found to support ponding for "long" or "very long" periods of time[32] based on soil descriptions in the database was 13,604 acres (Table 3). This number included some salt marshes and high elevation sites, but included only a limited number of taro growing lands in the state.

[31] USFWS Recovery Plan for Hawaiian Waterbirds, 2005.

[32] "Long" is ponding equal to 7 and not more than 30 days per event; and "very long" is equal to 30 days or more per event.

TABLE 3. HYDRIC SOILS SUPPORTING PONDING BY ISLAND IN 2006

Island	All soils supporting ponding (acres)	Salt marsh (acres)	Tropaquept soils[33] (acres)	Rocky soils with ponding 0-1,000 ft elev. (acres)[34]	High elevaton rocky soils with ponding 1,000-3,500 ft. elev. (acres)[35]
Kaua'i	1,301				
O'ahu	1,763		595		
Moloka'`i	2,459	318			
Maui	936	187			
Hawai'i	7,145		683	1,097	5,365
Total	**13,604**	505	1,278	1,097 (Hawai'i only)	5,365 (Hawai'i only)
Unlikely to support AS	5,365				?
Possible AS habitat	8,239	?	?	?	?

Based on the above information, this Plan suggests that the minimum acreage that should be considered at risk for invasion by apple snails is approximately 11,000 acres statewide (Table 4 below).

TABLE 4. MINIMUM ESTIMATED AT RISK HABITAT IN HAWAI'I.

Habitat	Estimated Acres
Cultivated taro lands	500
Fallow taro lands	670 minimum
Core and Supporting Waterbird Habitat (minus taro lands)	8,479
Other ponds, springs, ditches, culverts, and estuarine habitat	unknown
rKFD soils (`a`a lava with springs, ponds and other water above and below ground)	1,097 (Hawai`i island only)
Total	**10,746+**

[33] Tropaquepts are "poorly drained soils that are periodically flooded by irrigation in order to grow crops that thrive in water. They occur as nearly level flood plains on the islands of O'ahu and Maui. Elevations range from sealevel to 200 feet" (NRCS Soils description). These are typically taro growing lands.

[34] rKFD Keaukaha extremely rocky muck. (NRCS Soils description)

[35] rKGD Keei extremely rocky muck. (NRCS Soils description)

This number clearly demonstrates that the apple snail problem is no longer an agriculture or taro farmer problem. In fact, taro lands represent less than five percent of all at-risk acreage in the state. The majority (95%) fall under the responsibility of state and federal agencies.

2004 - 2006 Field survey

Surveys and collections of *Pomacea canaliculata* have been conducted on all of the main islands sporadically since 1989. The most thorough survey on any island was conducted in 1998 for O'ahu (Lach and Cowie, 1999). The most recent surveys to determine the spread of *Pomacea canaliculata* were conducted from 2004 through 2006 on the islands of Kaua'i, Maui, Moloka'i, Lana'i, O'ahu and Hawai'i as part of an economic impact and species dispersal study funded by USDA.[36] Researchers visited the most likely snail habitats on each island, collected specimens, and GPS'd locations from each infested site. The surveys spent greater time on islands that had only been briefly surveyed in the past and did not revisit many O'ahu sites. They also did not cover 100 percent of the potential habitat for the snail.[37]

The total number of waterbodies in which *Pomacea canaliculata* has been collected and/or recorded on each of the following islands for all years of survey are:

Kaua'i	4[38]	Lana'i	1
Maui	8	Moloka'i	0
O'ahu	28	Hawai'i	2

During the 1998 O'ahu survey, a total of 139 sites in 98 bodies of water were investigated, and snails were found in 19 of these waterbodies. By 2005, the total number of locations on O'ahu infested with apple snail had risen to 28 sites. The larger question of whether apple snails are found outside lo'i kalo is clearly answered by the 1998 survey, which focused on non-taro growing areas, and confirmed by the 2004-2006 field survey.

Lach and Cowie (1999) wrote "we do not believe the snail has reached its full potential distribution on Oa'hu. Many freshwater habitats appear suitable in terms of flow, vegetation and available oviposition [egg laying] sites, but are not yet colonized." Existing evidence suggests that more attention is needed on areas immediately upstream of lo'i kalo or any other known population. Work by the DLNR-Division of Aquatic Resources on a freshwater database and continued survey may improve our ability to that answer questions regarding the full range of habitats susceptible to invasion (A. Montgomery, pers. com. 2005).

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[36] Field survey was conducted by Robert Cowie and Ken Hayes (UH CCRT) and Penny Levin under a USDA T-Star grant.

[37] Access to sites was occasionally limited by lack of roads or trails, difficult terrain or inability to reach a landowner. Survey focused on the lowest reaches of streams and flat, taro-growing lands. Springs and ponds were assessed where known. Limited funding constrained the ability to survey all potential sites.

[38] Taro farmers recognize 12 additional waterbodies infested with *P. canaliculata* (R. Hariguchi, pers. com. 2006); voucher specimens have not been collected and documented at these sites yet (Cowie, pers. com 2006).

4.1. Distribution pathways

The spread of *Pomacea canaliculata* can be attributed to four types of events: deliberate or accidental introduction; escape from contained areas or ponds; natural downhill colonization from the point of introduction and following the flow of water; and back flooding. The latter three result from the snail's own self-propulsion assisted by water; the first is a direct result of human transport, and possibly by birds such as cattle egrets (*Bubulcus ibis*), 'auku'u (*Nycticorax nycticorax hoactli*) and some endemic waterbirds.

Introductions to the state and from island to island are attributable solely to deliberate transport by people. Based on farmer recall, earliest arrival in taro patches in Hawai'i for *P. canaliculata* is estimated at 1983-84.[39] As described above in Section 2.2, the likelihood that these introductions to taro patches were the result of impacts from the aquatic pet trade is small (see footnote no. 7 and 8; pg. 17).

Movement from ahupua'a to ahupua'a on each island is also overwhelmingly attributable to human introduction. After the snail's initial discovery in lo'i kalo, apple snail culture was encouraged as a supplementary income project (beginning in 1989). These cultured snails were transported rapidly from backyard tank projects to taro patches. Unaware of the aggressiveness of the pest, *Pomacea canaliculata* was conveyed from patch to patch in Maui, and from Maui to Kaua'i in the span of three years. The Filipino community in Hawai'i has been significantly involved in the snail's dispersal to numerous locations adjacent to or in taro fields, ditches and 'auwai that feed lo'i, ponds, springs and wetlands. Introductions have also been malicious, as in cases on Kaua'i where buckets of apple snails were dumped at Ke'e near Limahuli Stream, Waikoko (Dixon-Stong, 1995) and in the Hanalei Refuge (1995-96).

From time to time, farmers observe cattle egrets and 'auku'u flying off with snails suggesting this may be another avenue of infestation. Farmers also note that the transfer of snails into taro patches is sometimes linked to native birds, including the mudhen (*Gallinula chloropus sandvicensis*). The bird inadvertently brings snail eggs into taro fields through its nest-building activities, plucking stems which have egg clusters attached from weedy areas to add to its nest.[40] The frequency of such occurrences is unknown.

Azolla, a floating aquatic fern that is present in some taro systems, is used by farmers to cool water temperatures and suppress weeds. It also provides additional nutrients to the patch as it dies. The plant moves easily on surface water through the lo'i system, or by bucket transfer when introduced to new fields, and may be a means of transport for smaller snails between patches in a limited number of cases. Where high densities of snails occur azolla is typically not present, having been consumed by the pest.[41]

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[39] This arrival was likely an unpermitted and undetected introduction directly from the Philippines.

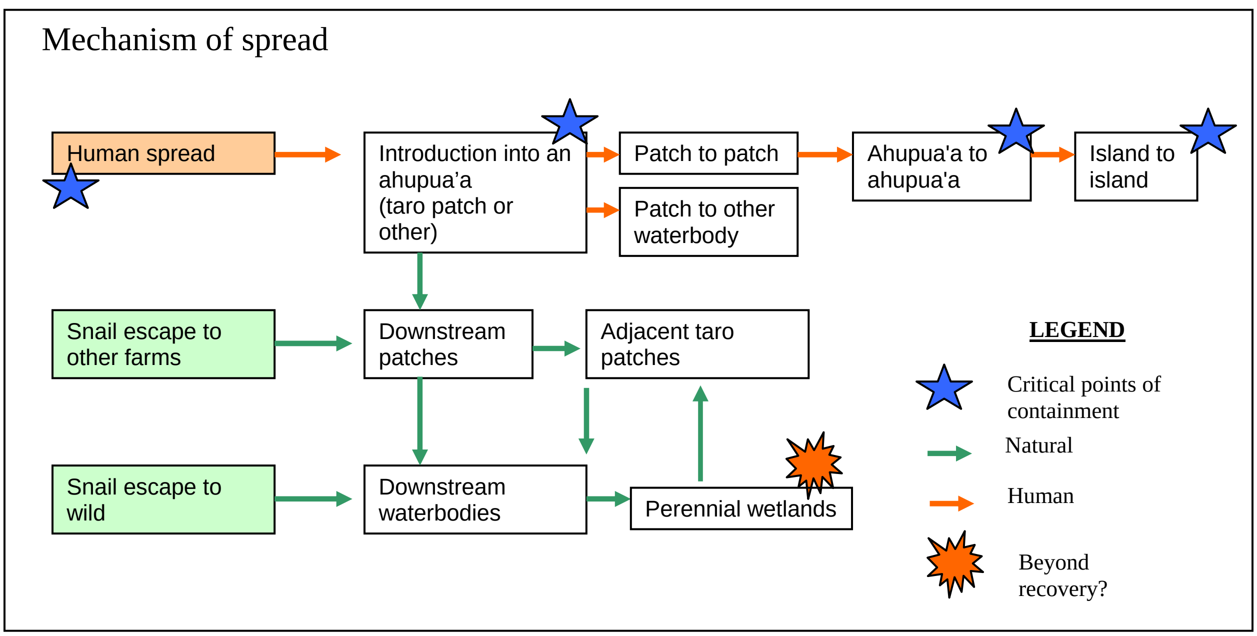
[40] At one site where a farmer rigorously suppresses apple snails and eggs in each patch and has reduced damage to taro to almost nothing, reintroduction through egg clusters in the vegetative material in mudhen nests has occurred several times.

[41] *Pomacea canaliculata* is also recorded as attacking Azolla in the Philippines and Japan (Cowie 2002).

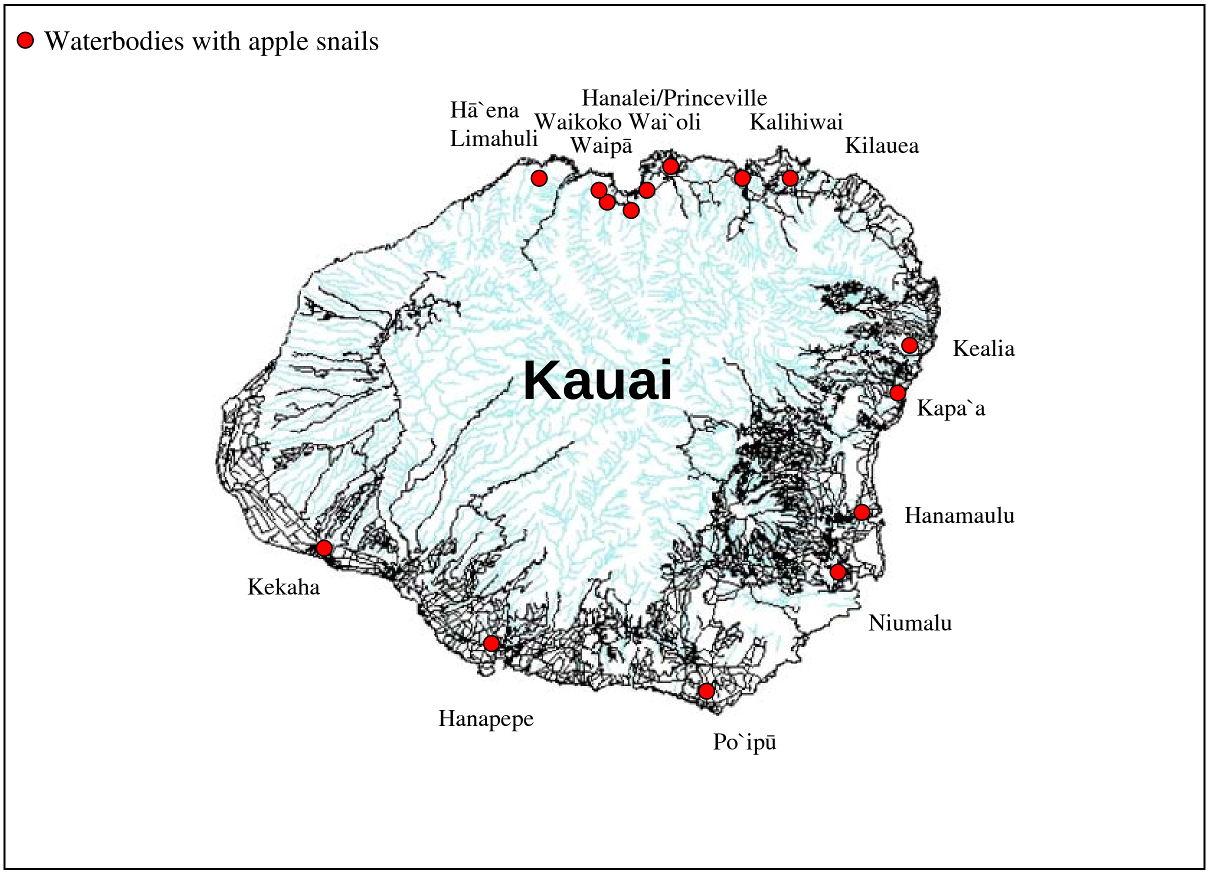
Flooding from heavy rains disperses apple snails over low-lying areas. In such cases, snails are flushed out of one site and distributed downstream across lo'i and waterways. This type of event may create especially high densities in areas where flood waters slow and pool. High tides at the mouth of a valley can also push water back up the system, further dispersing the snail throughout a broad area.

Fig. 1 illustrates both the primary mechanisms and pathways of snail distribution and the critical points of containment in control efforts. Once apple snails are introduced into a freshwater-based system they can 'walk', roll or float with any water movement further down the system. Flooding may either flush snails out of the system or cause ponding which can distribute snails across a broader area. Unfortunately, for the state and many districts on each island, apple snails are already present. However, the island of Moloka'i is currently free of this pest species and, with vigilance, still has a chance of remaining so.

FIG. 1 PRIMARY MECHANISMS OF SPREAD OF *POMACEA CANALICULATA* IN HAWAI'I



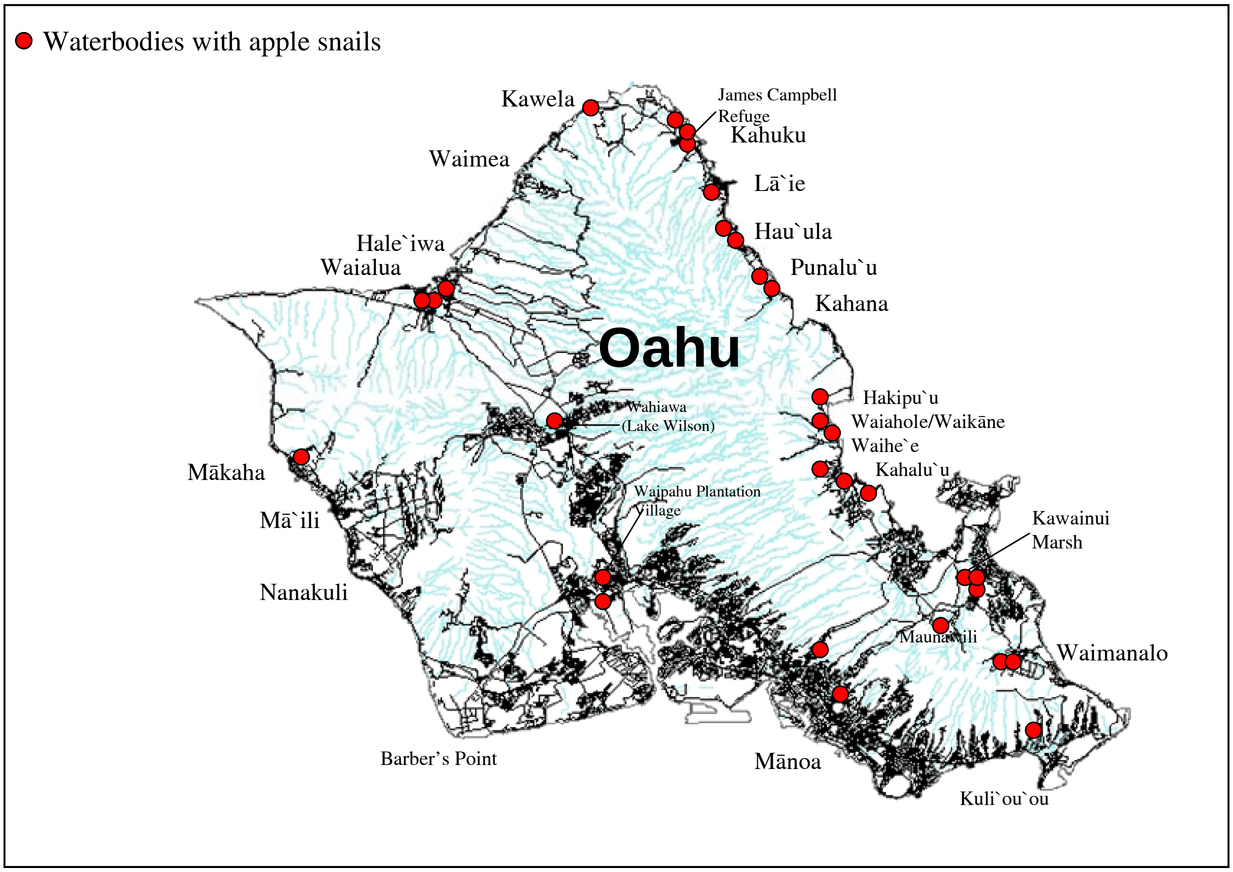
MAP 1. *POMACEA CANALICULATA* DISTRIBUTION, ISLAND OF KAUA'I



Points on the map represent waterbodies (such as a whole lo'i system, stream stretch, ditch, pond or wetland area) where snails are present (taro farmer observation and scientific survey). The table below represents only those locations where snails were collected during survey work (vouchered) and not all locations where *Pomacea canaliculata* is known, nor actual introduction dates.

Surveyed locations (supported by vouchered specimens) by year: Kaua'i
Waipā Valley 1991
Hanalei Center 2005
Kūhiō Hwy, Ha'ena State Park 2005
Hanalei Hwy, Taro Patch along the road. 2005
Kekaha ditch near Polihale State Park 2005
Hanalei Wildlife Refuge and taro farms 2005
Irrigation ditch running along side of Kaumuali'i Hwy just before Polihale State Park - Across from radar station. Mauka (up hill) side of the road 2006
Irrigation ditch running under Kaumuali'i Hwy past Waimea 2006
Kawiwiele Sand Mine Bird Sanctuary Project 2006

Map 2. *Pomacea canaliculata* distribution, Island of O'ahu

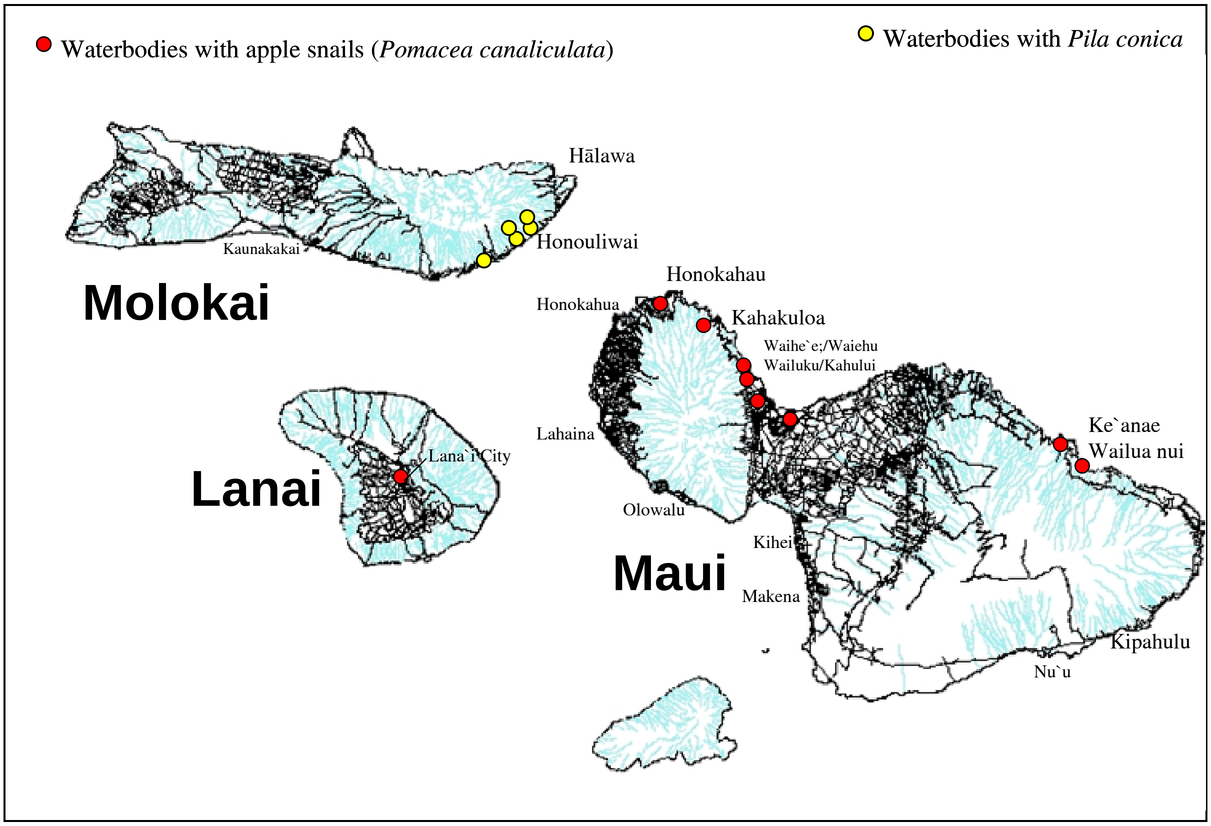


Points on the map represent waterbodies (such as a whole lo'i system, stream stretch, ditch, pond or wetland area) where snails are present (taro farmer observation and survey). The table below represents only those locations where snails were collected during survey work (vouchered) and not all locations where *Pomacea canaliculata* is known, nor actual introduction dates.

Surveyed locations (supported by vouchered specimens) by year: O'ahu
Kualoa/Hakipu'u, taro patch 1993
Waikāne Stream, at Kam Hwy bridge 1995, 100m upstream 1998, 300m downstream 1998
Waipahu Plantation Village, lo`i kalo 1998
Waialua, ditches both sides of the road 1998
Haleiwa ditch, north side of Waialua Beach Rd, east of Haleiwa 1998
Haleiwa, roadside ditch, 66-240 Waialua Beach Rd. 1998
Haleiwa taro fields, south side of Waialua Beach Rd 1998
Kawela Stream at bridge at Kam Hwy, west of N. Hanopu St 1998
Kahuku, in ditch along unpaved road leading into Campbell Refuge 1998 and 2004
Kahuku, in stream west edge of Campbell National Wildlife Refuge 1998
James Campbell National Wildlife Refuge 1998
Lāi'e, Hawaii Reserves Inc. ditch around lo`i kalo 1998
Lāi'e, unnamed stream connecting 'Ihi'ihi and Kahawainui streams, Pohaili St. 1998
Punalu'u, ditch along Punalu'u Valley Rd and ditch along taro patches, same road 1998

Surveyed locations (supported by vouchered specimens) by year: O'ahu
Kawainui Marsh Stream below Hanale Place 1998
Kawainui Marsh, off Kapa'a Quarry Rd 1998
Waimānalo, Kahawai Stream at Mahailua St. bridge 1998; bridge Kalaniana'ole Hwy 1998
Maunawili Stream, bridge, road to the country club 1998
Kapakahi Stream, downstream from Farrington Hwy 1998
Nu'u Freshwater Fish Reserve, at weir and upper lake 1998
Wahiawa Reservoir (Lake Wilson) near Schofield main entrance 1998
Mānoa, University of Hawai'i Quarry Pond 2003
Stream in Hawaii Kai, near Hawaii Landscape Nursery, Oahu 2005
Waihe'e Stream Kahalu'u along side of Hwy next to beach 2006

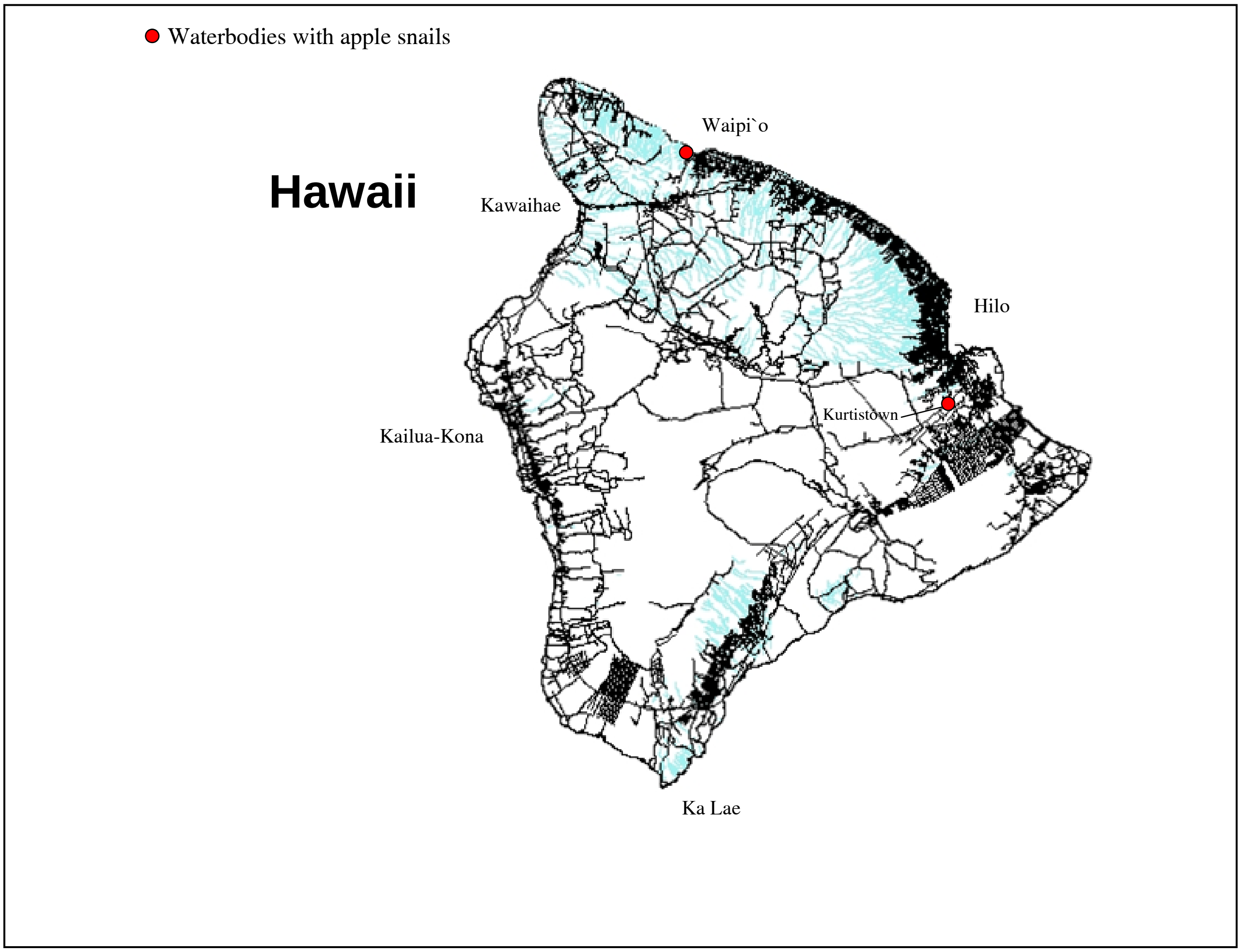
MAP 3. *POMACEA CANALICULATA* DISTRIBUTION, ISLANDS OF MAUI, MOLOKA'I, LANA'I



Points on the map represent waterbodies (such as a whole lo'i system, stream stretch, ditch, pond or wetland area) where snails are present (taro farmer observation and survey). The table below represents only those locations where snails were collected during survey work (vouchered) and not all locations where *Pomacea canaliculata* is known, or actual introduction dates.

Surveyed locations (supported by vouchered specimens) by year: Maui and Lana'i
Maui
Kahakuloa-Honokōhau, lo'i, Pole #3 2004
Kahakuloa, lo'i 2004
Ke'anae, lo'i kalo 2004
Wailuanui, lo'i kalo 2004
Waihe'e River, Maui 2004
Waiehu, Beach Rd 600ft elev. 2004
2555 Kahekili Hwy 2004
Paukūkalo, lo'i 2004
Paukūkalo, springs makai of Waiehu Beach Rd. Elevation 2004
Kahului, unnamed drainage canal, Alamaha st area, to Kanahā Pond 2004
Lana'i
Kō'ele Golf Course ponds, Lana'i 2005

Map 4. *Pomacea canaliculata* distribution, Islands of Hawai'i



Points on the map represent waterbodies (such as a whole lo'i system, stream stretch, ditch, pond or wetland area) where snails are present (taro farmer observation and survey). The table below represents only those locations where snails were collected during survey work (vouchered) and not all locations where *Pomacea canaliculata* is known, nor actual introduction dates.

Surveyed locations (supported by vouchered specimens) by year: Hawai'i
Waipi'o, lo'i kalo 2004
Kurtistown pond 1992; site not found in 2004

5. An assessment of historic and existing apple snail control methods in Hawai'i

In 2005, the IUCN Invasive Species Specialist Group (ISSG) database described the potential for apple snail eradication and the history of control, as such:

> *Eradication of established populations is probably not possible. Numerous measures have been tried in attempts to control apple snails in agricultural settings. These include: widespread use of pesticides, with serious environmental and human health consequences; biological control, notably the use of fish and ducks; a range of cultural and mechanical control measures. None has proven entirely effective, safe, and economically viable. None is likely to be appropriate in natural ecosystems. In rice and taro fields, hand picking is a successful method to control apple snail populations without harming the environment. The disadvantage is that it only works when done on regular basis…*

A worldwide conference on apple snails in Taiwan (October 2004) discussed what was known regarding control methods. The conference confirmed the above sentiments. It appears that no new discoveries in successful control practices have been added since these initial statements were made.

A relatively limited amount of resources have been applied to the issue of controlling apples snails since its arrival in Hawai'i 25 years ago, with the predictable result of a dramatic increase in the distribution and population of the snail.[42] Both research and field control programs have been funded in the past with minimal success; partially due to inconsistent support and application, or single solution approaches. This section describes the practices that have been tried in Hawai'i and their degree of success, given available information.[43]

What do we know?

5.1 Salts

Snails are somewhat tolerant of brackish and salt water. Where fresh and saltwater sources join (ie. at the confluence of a freshwater drainage and a brackish pond) snails are still able to establish themselves. Field testing suggests snails need to be submerged for longer than 48 hours. Flushing fields with salt have been shown to kill off snails at Campbell National Wildlife Refuge (O'ahu); however, subsequent changes in vegetation towards more brackish water adapted species occur. Inundation destroys soil productivity for agricultural crops. Farmers have thrown salt on collected snails to kill them; some take the added step of stomping on them, or crushing them to break the shells first.

[42] The pattern of providing limited resources to address incipient species in the early stages of population establishment in Hawai'i (ie. salvinia, miconia, coqui frogs, gorse, strawberry guava, to name a few) has resulted in significant ecological losses and costly control efforts throughout the islands. Only recently have the economic costs to broad sectors of the community begun to be evaluated (T-STAR Economic Impacts of Invasive Species Project; 2004-2006).

[43] Not all practices have been documented through scientific research. Only anecdotal information was available to describe some techniques, however, others, are based on consistent farmer observation.

Salt is successful in creating a barrier against slugs, but as with other barriers (see below), its use requires constant monitoring. Covered salt troughs may prevent apple snail movement from one lo'i to the next. However, due to the wetter, rainier climates of taro-growing areas and the need for the troughs to be located on the ground (around the lo'i) where splash can occur during heavy rains, the practicality of this method remains untested.

Potassium chloride, different from sodium chloride (pure salt), is sometime used as a fertilizer. Application of this compound results in a "big foot" response and subsequent death in the freshwater Asiatic clam *Corbicula fluminea* which is found in irrigation systems, reservoirs and 'auwai in Hawai'i and Maui (S. Hau, pers. com. 2006). No testing on apple snails or snail egg clusters has been done. It has been suggested that it may have the ability to breakdown the calciferous shell that protects the eggs. This compound may be worth further study.

5.2 Copper

Copper is toxic to slugs and snails. Copper strips have been generally used as a barrier in gardens to deter these pests from planted beds. This is an effective method on a small scale; however, its use is cost-prohibitive on the scale of most taro farms.[44] It is only effective where snails have not yet infested a site. Water flowing between lo'i is the main source of infestations from one patch to the next, rather than snails traveling over ground. Copper filters at inlets and outlets to taro patches have not been tested. It is possible that this might be effective in preventing adult snails from passing between lo'i but may have little impact on juvenile snails (see discussion 5.27 Screens and bags, below).

The temptation for theft is very high (copper theft is a costly nuisance to utility companies and other businesses in Hawai'i because of its high recycle value).

5.3 Copper sulfate

Copper sulfate ($CuSO_45H_2O$) is known as a molluscicide for use in irrigation ditches and has been in use for the last century; however, little research has been done on the impacts to aquatic biota (Hill 1999). The Hawai'i Department of Agriculture began testing the efficacy of copper sulfate, traditionally used as a micronutrient fertilizer or fungicide in agriculture in the United States (Ibid), for apple snails control in taro patches on Maui and Kaua'i in 1990 and 1991.[45] A temporary special use permit was issued by the U.S. Environmental Protection Agency (EPA) to the HDOA from 1994-1996 to allow for distribution and use to taro farmers on the basis of existing mainland use permits, its availability and low cost.[46]

[44] Hard to find in Hawai'i in large quantities; on the mainland 500ft of 3in copper strip costs almost $200, not including shipping.

[45] Taro farmer interviews; HDOA.

[46] About $50/bag in 1996.

HDOA staff and extension agents applied copper sulfate to taro patches in Maui and Kaua'i for several years, with varying degrees of success. Additionally, farmers were able to acquire the compound from HDOA and receive training in how to apply it to their fields specifically for apple snail control for a period of time. The label and reporting for this product were highly restrictive and it seemed that if applied properly would have little or no impact on the crop or the environment. One of the difficulties with the program was consistency in the rates of application (Matayoshi, pers. com. 2005). In the end, too many unanswered questions regarding its environmental impacts and a lapse in the EPA permit ended the program.

Copper has been used historically in Hawai'i as a fertilizer to prevent *phytopthera* (a fungal disease). It is an essential micronutrient in plants, however some phytotoxic effects have been documented in taro and other crops (Hill, Miyasaka and Yost, 2000). Copper and copper sulfate are absorbed and bound up with clay soils. After application, the chemical is evident in reflooded fields but it is not well understood how long it persists (S. Miyaska, pers. com 2005). A limited 1994 tissue culture analysis indicated elevated levels of copper in taro leaves.[47] Tests conducted in the late 1990s in Hawai'i revealed that early signs of copper toxicity are visible in an olive-green color and sometimes dieback on leaves or leaf tips for about two weeks.[48] Total dry weight of corms was significantly reduced as copper levels increased, especially for the variety, Lehua maoli.[49] Root length also declined; with a shift towards shorter, thicker roots. Chlorophyll content declined at higher levels of copper suggesting impacts to photosynthesis rates. Copper concentrations in leaf blades did not increase, but were observed in root tissue (Hill, Miyasaka and Yost, 2000). Hill's research (1999) cites studies which indicate that copper becomes bound up in soil eventually resulting in toxic levels which appear to remain in surface soils. Studies also show a wide range of sensitivities to copper among aquatic animals and algae (1999:9-10). However, Hill concludes in his copper sulfate studies that while "there was no evidence of detrimental effects of [copper sulfate] on taro yield…a significant elevation of Cu concentration in drainage waters is cause for concern" (1999:59). Hill further concludes that "applying [copper sulfate] according to [EPA] special use permit instructions…led to Cu loading into the downstream environment, but its biological significance is unknown" (1999:80).

In 2006, the danger of over-application still exists and there is still no clear understanding of the full implications of copper sulfate to Hawaii's ecosystems. Cu toxicosis (poisoning) has been documented in Canadian geese (Henderson and Winterfield. 1975); suggesting the impact on nene (*Branta sandvicensis*) would be similar. Farmers and environmentalists continue to have questions regarding potential Cu buildup in lo'i soils and downstream impacts to estuarine and coastal reef systems, as well as retention in humans consuming taro grown using this chemical (particularly nursing women and young children). Questions of whether this compound did or would affect the taste of taro and poi were also raised.

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[47] Letter to HDOA 25 May 1994.

[48] For growers who harvest weekly for lū'au leaf this posses a risk of potential economic loss; off-color or dying leaves can not be sold.

[49] This has implications for reduced corm weight at harvest and therefore reduced yields.

5.4 Molluscicides

Iron phosphate (ferric phosphate) is a naturally occurring chemical in soils. It forms the basis for a relatively new, patented molluscicide available in Hawai'i (EPA Registration # 67702-3) sold under the brand name Snail Bait™. It must be ingested to work and is applied at a recommended rate of 0.25-1.0 pounds per 1,000sqft. All research to date has been for terrestrial species of mollusks and not aquatics. According to the HARC Final Report to SARE (2004), the EPA “waived a number of ecological effects toxicity data requirements because of the known lack of toxicity of iron phosphate to birds, fish and non-target insects, its low solubility in water and the conversion of the ferric form to the even lower soluble ferrous form in soil.” No molluscicides are approved for use in freshwater in Hawai'i.

5.5 Organic compounds

Neem and papaya extracts

Neem is currently used in nurseries and organic farms in Hawai'i. The plant has a centuries old history of use in South and Southeast Asia as an insecticide (among other things). The active ingredient in neem that gives it pesticidal properties is azadirachtin. A rapid literature survey for this Plan, indicates the use of neem in water-based agricultural systems was primarily as an additive during fallow periods but has been used in rice and taro trials in efforts to control apple snails.

The Hawai'i Agriculture Research Center (HARC) investigated the use of neem (cake, oil and leaves) and papaya extract for apple snail control from 2001 through 2004. HARC laboratory experiments found snails stopped eating from the first day of exposure to neem cake with neem oil and exhibited 96% mortality within 9 days.[50] In trials where apple snails were fed on fresh neem leaves, the number of egg cases produced after 9 weeks appeared to greatly increase.[51] There is no evidence that given a choice between taro, other wetland plants and neem, that apple snails would prefer neem as a food choice.

Field experiments indicated water level depths have a significant impact on neem efficacy. In one inch of water, snails showed 85% and 96% mortality respectively within controlled enclosures in two lo'i systems over 7 days. While “no phytotoxicity was observed by researchers in the plants throughout the test period”, testing for absorbed toxins within adult taro plants was not reported. Additionally, HARC reported no aquatic organisms could be found in the lo'i thereby preventing them from testing neem’s impact on other aquatic biota (SARE Final Report 2004).[52]

[50] Mel Jackson, P.I. for HARC apple snail control trials in a presentation to taro farmers (Kaua'i Oct 2004).

[51] Mark Comstock, in a presentation to taro farmers (Kaua'i Oct 2004) described neem as needing 4-5 years to reach a size capable of producing leaf and seed to meet farm demands. The trees does well in mesic climates below 2,000ft elevation. While seeds require drying and soaking in warm water at least twice to germinate (easily achieved in warm, wet climates such as Hawai'i), their germination rate is estimated at 90% and should serve as a cautionary in considering establishment of this species.

[52] Whether this was due to the impoverished conditions created by dense populations of apple snails in this lo'i or by application of neem was not clear from this report. Careful aquatic fauna and microfauna survey prior to

Proponents of organic farming and neem indicate there would be negative impacts to aquatic biota, including microfauna, from the plant's insecticidal properties. The EPA's Biopesticide Division decision based on HARC research and additional findings was that neem extract "would require a full registration procedure…[including] toxicological studies on non-target organisms and a full residue study on the crop, before the extract could be registered for use on wetland taro" (SARE Final Report 2004). HARC determined that "a study of this nature usually costs millions of dollars and takes many years to complete."

One of the principals of good stewardship outlined by 'Onipa'a Nā Hui Kalo includes returning water to the stream from which it was borrowed ('Onipa'a Nā Hui Kalo 2004). Taro farmers expressed concern for neem extract residues that might recycle back into streams. Closing and resting water in individual lo'i during treatment may not be enough to neutralize azadirachtin compounds for stream biota and may negatively impact important microfauna within the lo'i.

An extract developed from green papaya shows limited use for apple snail control. A crude latex showed 100% mortality in 48 hours in laboratory aquariums, however, in the field, the enzyme responsible for response in the lab breaks down quickly, possibly due to sunlight and absorption by organic matter in lo'i mud. It also may not act quickly enough to overcome adult snails when young taro plants are in the field.[53]

Field trials for neem and papaya compounds required draining water from a taro patch to a depth of 1 inch and closing off additional water for 3 days. Uncirculated, shallow water supports the growth of taro diseases, particularly *phytophthera* and pocket rot. Testing for impacts to other aquatic organisms has not been done on either compound.

Both extracts are expensive on a large scale. Pure neem oil, the strongest source of azadiracthin, ranges from $11.50/liter to $22/quart wholesale. Neem cake is cheaper at $4.50 to $14.50/kg. [54] One estimate suggests an application of 2 tons of neem cake per acre, making the use of this compound economically unfeasible.

Other compounds

HARC is currently investigating the potential properties of mugwort and yucca compounds, along with continued testing of papaya extract. Preliminary results may be available in mid-2006 (M. Jackson, 2006).

There has been some discussion that the fertilizer urea kills apple snails and other lo'i pests, however, no documentation is available on rates of application or effectiveness. Lo'i waters are connected to streams, wetlands and coastal reefs. Over-fertilization of any kind can alter

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trials, along with daily counts of waterbird foraging within trial lo'i would add significant insight into neem impacts.

[53] HARC trials with one farmer were terminated due to the loss of young taro plants to apple snails early in the trials (of 56 only 5.5 remained).

[54] Wholesale prices directly from Nicarauga and India (the primary source for neem products) and through intermediary companies in the U.S.; not including shipping costs.

water and habitat conditions and impact native aquatic fauna. Farmers cautioned that excessive weed growth could influence dissolved oxygen content, pH, aerobic/anaerobic balances in the water and the lo'i, as well as compete for other soil nutrients with taro plants.

Taro farmers in Maui have discovered a promising control in an organic fertilizer compound derived from vegetable saponins that has an immediate exterminating affect on apple snails (complete kill in a lo'i in under 10 minutes with low-level applications). It is low cost, easy to apply, requires only one or two applications per year when timed properly, and can be produced locally. The compound shows excellent promise, however, funding to conduct scientific trials to quantify efficacy and determine impacts to other aquatic organisms has not been available.

5.6 Baiting

Baiting, in combination with trenching around the edge of a patch or in a small ponding area, serves to draw apple snails to a single site for easier removal. Most farmers in Hawai'i do not intentionally bait for snails.

Snails are generalists in their eating habits and most vegetative material will attract them, although laboratory tests showed a reduced preference for water hyacinth and little damage to this plant in the field (Lach et al, 2000). In Southeast Asia, jackfruit, chicken manure, rotten vegetables, ong choi, honohono grass, and coconut have been used. Grass clippings and neem leaves have been tested as well. Neem serves the double purpose of killing the snails once they consume the leaves, however, research showed an increased in egg laying after feeding on neem leaves.[55]

Farmers can use whatever material is available without cost and little additional labor. Baiting can be considered a no cost enhancement for dry-down techniques if congregating snails are removed regularly to prevent egg laying.

Sticks have been placed upright in the mud as ‘bait’ for snails laying egg clusters. Sticks are removed and replaced as they are used by snails. The idea behind this method is to facilitate easy removal of future generations of snails. Where taro plants and weeds occur, snails appear to prefer living material for egg-laying. Inspection, removal and replacement must occur daily and represents additional work which must be separated from weeding and other activities. Removal of eggs is not enough; clusters must still be crushed to prevent hatching. Stick placement in the lo'i is not practical at normal 18-24 inch spacings. Once taro plants fill out there is little room between rows. Sticks placed under the leaf canopy can damage roots and puncture leaves (a negative impact for lū'au patches)

5.7 Screens and bags

Screens and bags have been in use for apple snail control in Hawai'i successfully for a number of years. Farmers use a variety of materials, including onion bags, window screens,

[55] Mark Comstock, in a presentation to taro farmers (Kaua`i Oct 2004)

metal grates, oven and refrigerator racks, and windsocks.[56] Bags are typically replaced each time they become filled. Screens are cleared by hand. This method is effective to varying degrees, however, it presents two problems.

Screens and bags increase the need for a farmer to be constantly present on the farm. The finer the mesh of the bag, the more snails and other debris it collects. Screens and bags rapidly fill or get blocked in moderate or highly infested areas. They require frequent monitoring and cleaning even in moderately infested patches. Left unattended, particularly at night, the pile up of snails against a screen or in a bag can cause flooding, resulting in damaged crops and banks.

To address this problem, some farmers use rougher mesh material (ie. onion bags) or more open grating (ie. metal racks). This usually traps adults. The likelihood that juvenile snails will pass through undeterred is dependent on the fineness of the mesh. Young snails colonize downstream sites as easily as adults.

5.8 Snail barriers

Exclosures have been built in Hawai'i to protect native tree snails from the cannibal snail, *Euglandina rosea*. The fencing contains a trough filled with a repellent or toxic substance over which any snails attempting to enter the exclosure must pass. These barriers have had some success but require constant and vigilant monitoring and maintenance (ISSG Database 2006). Tested compounds include chili peppers (Star Bulletin 2000) and a toxic bait from snails in the genus *Pomacea* (Chhun 2002). Untested barriers include permanently roughened surfaces or fine sand-like particles that might damage the snail's foot and require less field maintenance.

Constructed barriers have not been tested for use in control of *Pomacea canaliculata*. Most taro-growing lands are found in windward, wet locations. High rainfall would likely pose a problem in maintaining the effectiveness of baits since barriers would need to be located at ground level where rain splash can wash away the bait; however, this barriers may merit further study for clean areas immediately mauka (above; upland) or makai (below; towards the ocean) of infested sites.

5.9 Pest-for-Profit programs

Economic incentive programs that promoted the use of apple snails in gourmet restaurants and encouraged enterprise development around the raising and processing of the snails have been controversial. They have had minimal success and only when funding was available to subsidize activities. In at least one case, the attempt to address snail infestations in an economically viable manner (by collecting and selling the snails) resulted in both misunderstanding and animosity within the taro farming community. When project money ran out, the project halted. It left behind a lasting distrust. Initial programs encouraged local chefs to design cuisine that would entice high end consumers to the table. Its appeal did not

[56] The windsock design was introduced to taro farmers by Dr. Clinton Campbell, HDOA (Schlegel 1995).

grow as was hoped. Only one entrepreneur successfully developed a closed-system production facility for apple snails which does not depend on maintaining an outdoor population. There is at least one additional “snail farm” and possibly three in the state, however, the degree to which escape prevention practices are in place is unknown.

From 1996 through 1999, a Maui project provided a $0.50 per pound bounty for snails gathered from lo'i kalo in Wailua nui. The Na Moku Aupuni O Ko'olau project, cosponsored by DHHL, Maui County, HDOA and the Small Business Innovative Research program, and run by UH SEA GRANT, was an attempt to deal with an overwhelming pest in what appeared to be a win-win situation (potential eradication and additional income). The project was successful, to a degree but not sustainable. While the project was funded, there was a significant reduction in apple snail populations and subsequent improvement in taro yields. However, when funding lapsed, so did farmer efforts to harvest the snails. Immediately after 1999, apple snail populations began to increase again. In 2006, snails have returned to higher levels.

In evaluating the program’s goal to develop a “Hawaiian escargot” market, several issues emerge. Snails fed on catfish meal or chicken feed rather than wild collected specimens were preferred by chefs in high end restaurants on Kaua'i and O'ahu for their flavor and texture, indicating that if there was a market to be developed, snails gathered from the taro patch would not be of high value and would require additional “farming” and feeding to improve their marketability. Testing was also done to assess the production costs of snails which must be parboiled and cleaned (only the foot is used). A single person can process about 4 snails per minute, or 38,400 snails per month (Tamaru, Ako and Tamaru. 2004:57). By the above reckoning, based on numbers provided for apple snail population densities in Hanalei, Kaua'i from this same program, it would take one person an estimated 3.7 to 14.75 years (44.25 and 177.08 months respectively) to clean the snails from 30 acres, provided no additional snails were added to the population during that time. Conversely it could employ 44 to 177 people for one year, however, given the low cost of the product and the lack of a substantial market either in Hawai'i or beyond, these are likely to be minimum wage, high turn-over jobs which would do little to add to the quality of life of families in Hawai'i.

A look at projected profit margins by studies conducted under the program reveals an assumption that chefs would pay a price equal to that of canned escargot ($12/lb) for apple snails (Ibid 2004). Only one processor sells finished product at $14 to $16 per pound. In Tamaru (2004), the snail is projected to bring a price of about $1 per pound at the farm gate with a retail value of approximately $6/lb. The Wailuku Sack N Save on Maui, sells cooked, packaged snails for an average $2.99/lb.; the product is available only occasionally. The product can also be found at Filipino grocery stores. Consumer prices in Chinatown markets on O'ahu are even lower.

The study also assumes a chef would use 1,015 pounds of snails per month, however, this is a desired state and not the reality. The demand for snails is small among chefs (Tamaru, pers. com. 2005).

One of the fundamental dilemmas of a pest-for-profit program is the creation of need for the pest, itself. Once a market is created, the goal of eradication becomes secondary to keeping a supply of the snails available as a marketable product. There is no incentive to completely eradicate them. In fact, in order to sustain the income generated by the snails without traveling beyond the farm, a steady population of the pest must be accessible. Attempts to use covered tanks on site have proven to be unable to prevent the snail from escape.[57]

There is some evidence that these programs may have precipitated further introductions to previously uninfested sites and perpetuated existing populations by creating a need to maintain a harvestable population (AIS Plan 2003; field observation). Of particular concern is the real possibility that the pest-for-profit program encouraged introductions to clean sites. It is not clear in Hawai'i State law whether the private cultivation of a listed invasive species is illegal or not.

Selling apple snails was considered a "last resort" option in an attempt to recover losses realized by snail destruction. Tamaru writes "Although the results were clearly encouraging, the one-time bounty placed on the wild apple snails that resulted in a dramatic decrease in the wild population was only possible because of the influx of grant funds…The most logical approach would be to bring forth a product that, at a minimum, generates enough revenue and covers all of the collection and processing costs of the activity. In other words, for the process to be successful, the creation of a new enterprise would be required." (2004: 59) Farmers have consistently made it clear during the development of this Plan that they do not wish to be "snail farmers", "duck farmers" or any thing else, other than taro farmers.

More state funds have gone into trying to create a subsidized industry from apple snails than has gone into direct eradication efforts; a rough estimate of over $135,000, not counting initial Maui County Economic Opportunities senior citizen projects (almost 40 percent of all funding in the last 16 years[58]).

Taro farmers across the state are very clear that this is not a program they wish to see pursued or supported further. Even those who are caught in the dilemma of needing to do something with the millions of snails in their patches are clear that to sell the snails – to suggest that a profit can or should be made from the snails – even as a high end food product, only encourages further misuse. Creating a composted fertilizer from the snails for use on-farm was offered as an alternative, however, most farmers feel strongly that here should be no economic incentive attached to the pest; thus removing any incentives for further spread. Closing that gap in this portion of the human dispersal chain may require further "disincentives" including greater enforcement and policy which makes the sale of the snail illegal in Hawai'i, even at local markets. As one farmer stated; "We want to eradicate it, not perpetuate it or to supply a market. A big question is, can taro farmers get rid of or control this snail but still allow the Filipino community a source of food? I don't think we can have it both ways."

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[57] Field observations 1995-2004.

[58] Inlcuding known federal, state, county, private and nonprofit funding. Excluding funding for the recent economic impact study and this Plan.

A full accounting of the real costs and profits of the apple snail industry against the huge losses the pest has cost the taro industry and Hawai'i as a whole, is called for.

5.10 Temperature

Freezing or boiling will kill *Pomacea canaliculata*, but this is not a viable option except on a small scale, perhaps to destroy aquarium snails. Steam augers designed to cook the roots of trees are unlikely to be efficient in wet mud. Ground sterilization, which cooks the soil, kills all living biota (beneficials and pests) and had no measurable impact on snails in limited experiments in the 1990s.
Increased in-stream water flows, with subsequent drops in overall water temperature can help to contain snail spread and reduce the amount of available preferred habitat for the pest, including in lower stream reaches where water flows have severely diminished in the last century.

Seasonal temperature changes are correlated to snail activity, with less activity and egg laying during winter months when temperatures are lower.

5.11 Electric shock

The use of electric shock to rid streams of invasive aquatic organisms has been somewhat successful in controlling populations of cichlids, other fish species, and introduced prawns. The method was tried by DAR staff using a backpack shocker and by taro farmers in Kaua'i without success (S. Hau 2006, pers. com.). Snails showed recovery within minutes after application of heavy electric shock (S. Hau, 2004 pers. com).

5.12 Dry-downs

Periodic lowering of water levels (called “dry-downs” in this document) and exposing the lo'i bottom has the effect of driving snails into the mud. This prevents continual feeding on taro corms, slows snail growth and temporarily halts egg laying.

Dry-downs periods vary greatly and farmers manage dry-downs based on specific site conditions including intensity of existing snail populations, rain and flooding cycles, the age and hardiness of taro plants, and how often they work the lo'i. Key dry-down periods occur at initial planting when huli are young and fragile and right before harvest. The number of dry-downs per crop cycle ranges from 2 to 20; with an average of 6-7 times per year. The length of time for each dry-drown varies from a few days to 2-3 weeks for some farmers.

Dry-downs are sometimes paired with the creation of a shallow ditch or small corner pond at the edge of each lo'i where subsurface water will pool. Snails congregate in these smaller water holes and are easier to pull from the patch. Baits can be added to increase snail catch. Muddy lo'i bottoms become firm enough during longer dry-down periods that the footprints of rats and mongoose are frequently observed within the lo'i as they predate on snails caught in these ponding areas.

Frequent dry-downs result in slower corm growth, more weeds and denser taro roots. This translates to more difficulty in pulling taro plants at harvest, competition for nutrients between taro plants and weeds, more time allocated to weeding, and smaller corms at harvest (see Fig.6 Apple Snail Impacts to the Environmental, Labor, Time and Cash Aspects of Growing Kalo).

5.13 Fallow and cover crops

The apple snail's biggest biological Achille's heel in Hawai'`i is to starve it of water.[59] Fallow is one of the cheapest means of reducing or completely eradicating apple snail populations, if the right conditions exist.

Where fallow works best is in lo'i that are able to dry out completely with no surface ponding. However, farmers report than even in heavy rain areas such as Hanalei, Kaua'i where ponding may occur for several days or more, significantly reduced snail populations can be realized. The key is for ponding to dissipate before snails are able to begin the egg laying process again (potentially a two week window of time).

A minimum of 1 year fallow has worked in areas were lands can be completely dried out and no subsurface water flows exist. Where subterranean water flows, ponds or caches exist; fallow can still work, but an extended time of to 2.5 to 3 years is needed for 100 percent mortality. Under the latter conditions, this length of fallow has proven to completely eradicate snail populations in Wailua, Mau`i. Fallows for shorter periods will serve to reduce snail populations but not eliminate them.

The key to effective fallow is management. This includes regular mowing and tilling prior to re-opening the lo'i.

Fallow cover serves several purposes including providing additional organic material for soil health. A soil cover with a tight root system may also make it more difficult for larger snails to come up out of the mud during short duration flood events. Sudan grass has been used by a few farmers in Hanalei with a regular mowing and tilling program.

Unmanaged fallow that masks long term ponding creates hidden habitat for the snails that will continue to re-infest adjacent lo'i.[60] Regular mowing of fallow fields reduces opportunity for this to occur.

While fallow does not cost much to implement, it has costs to farmer, miller and retailer income. A few farmers grow alternative crops such as vegetables, sweet potato, or dryland taro in fallow patches. Farmers, millers, and consumers prefer the taste of wetland grown kalo for poi. The currently preferred taro varieties do better in wetland than dryland conditions.

[59] Hawaii's tropical climate does support the opportunity to use the other weak point of the snail; to break the life cycle of the pest through seasonal freezes.

[60] Overgrown fallowed patches are consistently the source of uncontrolled snail populations in lo`i systems.

Two options for addressing this issue of income and meeting market demand while managing lo'i on long fallow include scheduling patch rotations so that some fields remain in production at all times, or opening new lands (with careful protocols for preventing new infestations). The first option may not be feasible for many sites based on how water flows in and through the lo'i system. If 'auwai are infested, neither option is suitable unless a clean route for water can be found. The USFWS Hanalei Refuge does not allow taro farmers to fallow for more than 30 days, nor do they allow farmers to rotate their fields with other crops unless it is a wetland crop, because of waterbirds. Unless there is a shift in policy, there are few options for these farmers.

5.14 Deep tillage and mechanized crushing

Deep tillage has become a part of snail control for some farmers with the intention that some of the snails would be broken up or brought to the surface to die. One to three tills are implemented prior to lo'i preparation. It appears to have some effects on reducing populations, however, no information is available on the impact to smaller snails or whether soil is broken up enough to crush a high percentage of the snails. Frequent deep tillage is not good for soil health over the long term. As an additional practice beyond regular tilling prior to planting, there are added fuel costs. Multiple tills are spaced out over several weeks; a longer timeframe is needed prior to planting.

Wetland managers sometimes use tilling and disking to manage non-native vegetation. This may have a limited affect on lowering apple snail population density.

Soil pulverizers have been tested in Hanalei but the rollers are unable to pick up the snails and crush them.

5.15 Trenching

Trenching was described earlier in conjunction with dry-downs. The basic practice involves making a shallow ditch around the inside edge of each lo'i so that as water is drained from the patch, snails gravitate to the trenches where water remains, making it easier for removal. It also keeps snails away from kalo plants because they prefer to be submerged in water. Farmers use several methods to create the trench. A simple technique for smaller farms is to tie a rope around the neck of a large round object such as an old kim chee jar or log, and drag it along the inside edge of the patch. The weight of the object is enough to create a shallow trench. The back side of a shovel will also work.

This method is only useful in conjunction with lowering water levels in the lo'i.

5.16 mounding

Several methods of mounding are found in traditional Hawaiian planting techniques for lo'i kalo; including one called pu'u 'one'one, a rounded, hill-like mound. Kalo is planted into the raised soil; the number of plants dependent on the size of the mounds. Long row mounds are also used and are easier to manage for larger farms. In this method, water in the patch remains at a low level so that taro roots within the mound stay wet, but snails are unable to attack the corm through the dirt. The plant is also protected because the snails do not climb onto the mounds above the water line.

The advantage of mounding techniques are a reduction in snail damage as well as reduced damage to taro roots from frequent snail picking activities. The total area available to the snails for its activities is also reduced. There is an increase in weed sprout on the mounds because soils are exposed above the waterline. Creating the mounds requires a different tilling and flooding process but once young plant roots are established, they are fairly easy to maintain through the cycle of the harvest. Mounds create opportunities for an increase in other pests in the lo'i, including rats and centipedes.

5.17 Hand-picking

Hand-picking is *the* recommended practice for all countries currently. Larger snails and egg clusters are pulled from the patch regularly. When the egg cluster is bright pink and wet looking, the adult snail that laid the eggs can often be found right at the base of the taro plant. In this control method, daily and weekly removal of snails and eggs are required. Egg clusters have a high mortality once knocked off into the water, however; clusters do float and some eggs may survive to hatching unless crushed. For farms with more than a few patches, this translates to significant increases in time and labor (see 6.3 Economic Impacts). Hand-picking has been documented to take as much as 40 percent of all time and labor spent to bring the taro to harvest (Levin et al, in progress). Farmers in the highest density snail areas of Hanalei estimate as much as 200 pounds of snails per acre are pulled from the lo'i several times a week during the summer. In Hanalei Refuge where few other alternatives are allowed, this method becomes back-breaking, never ending work even on a small scale. The toll that it takes on physical health and well-being can be high.

Traditionally, disturbance in the lo'i was supposed to be limited as much as possible to prevent damage to the roots of the plants. Damaged roots provide a vector for diseases such as pocket rot and *phytophthera*; both of which have increased in frequency in the last decade.

Snails hand collected from lo'i are typically dumped on the banks or at a composting location and crushed by stomping on them. Out of desperation, some small growers have been known to pour gasoline or bleach into the collection buckets to kill the snails prior to dumping. Large concentrations of dead snails draw rats and other vermin close to the taro patch. They also become a vector for bacteria and fungal pathogens. Where snails have been piled over long periods of time, a strong, rotten odor permeates the air. Increases in local rat populations are observed by farmers at such sites. This presents an additional set of health concerns for farming families. For many reasons, improvements to this practice must be found for places like Hanalei, including increased rat control.

5.18 Natural enemies (bio-control)

Many animals may occasionally consume apple snails as a part of their diets including birds, fish, turtles, crayfish, crocodiles and aquatic insects (Cowie 2002). True snail predators, for this discussion, are those who specifically seek out and consume apple snails as a significant portion of their diet.

The best known predators in other countries, and on the US mainland, include the Everglade snail kite (*Rostrhramus sociabilis*) which feeds almost exclusively on apple snails, the limpkin (a wading bird, *Aramus guarauma*), and Caiman lizards (*Dracaena guianensis*) (Cowie 2002). None of these species are appropriate for introduction to Hawai'i because of the impacts they would have on native biota. While the snail carries several parasites, including the nematode, rat lungworm (*Angiostrongylus cantonensis*) and the trematode, *schistosomes* (liver flukes), no parasites or pathogens have been found to be deadly or host specific. No fatal bacterial or viral pathogens are known (Cowie 2002). The search for natural enemies of *Pomacea canaliculata* has been ongoing for almost two decades with no success.[61] The chances of finding a host specific bio-control that would not affect other aquatic organisms or terrestrial snails are extremely low.

Most literature suggests that the snail has no natural enemies in Hawai'i. Several introduced species have been observed predating on small and medium-sized snails at some sites, including rats, mongoose, auku'u and cattle egret (farmer observation) and Tahitian prawns (Levin, field notes 2004). Domestic ducks have been trained to feed primarily on apple snails and are used by some farmers in the state effectively for this purpose.

At least one taro farmer has observed dead snails around nesting sites of 'alae 'ula (the Hawaiian gallinule). Koloa may also predate on smaller snails but have a much smaller bill and body size suggesting that if they did feed on *Pomacea canaliculata*, it would be to a much lesser degree than domestic ducks. The extent to which these native birds consume apple snails is unknown. Their potential as control mechanisms is limited at this time due to the small size of existing populations of these birds and the magnitude of the snail problem in wetland areas.

5.19 Ducks

Domestic ducks are a low cost and easy to manage method for apple snail control. They have proven to be the most efficient and effective means of reducing snail populations and the amount of direct physical labor required of taro farmers to maintain their crop. A number of breeds are used; Pekin are preferred in Waipi'o (Hawai'i), while Black Cayuga are preferred on Maui. Both are excellent consumers of the snail. These birds either can not fly or have little desire to, and take readily to patch management. Muscovies are not used because they tear up the banks of the lo'i and 'auwai system.

Ducks consume snails of most sizes except the very large ones, which are gathered by hand-picking. The advantage of this is their ability to go after snails at a much smaller size than

[61] Despite the Everglade kite's almost exclusive consumption of apple snails (*Pomacea paludosa*, not *P. canaliculata*) in Florida, the density of kite population that would be needed to knock back *P. canaliculata* populations the level of those in Hawai'i to manageable densities is unlikely. The birds are also both territorial and semi-nomadic in response to food availability; even if *P. canaliculata* was an acceptable substitute food, it in unlikely a nesting pair could possibly consume enough snails to keep such populations in check.

can be gathered by hand thereby reducing the number of snails that reach maturity. Coupled with hand removal of egg clusters, and careful timing, this represents the most thorough attack on both ends of the snail cycle compared to other methods. Some farmers have been able to reduce crop loss and damage due to snails to under five percent.

The number of ducks needed to maintain a series of patches once snail populations are reduced is fairly small. An estimated 12-15 ducks can handle several acres by rotating between patches during the course of each week. For large snail populations, a higher number of ducks are needed, in combination with other practices, until snail populations are reduced. Some farmers maintain a larger flock and introduce them to the lo'i less often. When snail numbers get extremely low, care should be given to limiting the amount of time ducks spend in the lo'i to prevent damage to taro plants as the ducks will seek out other food sources to replace the snails in their diet.

Ducks are lost to dogs, theft, occasionally mongoose, and old age. A single case of duck loss due to botulism was reported (Levin, field notes 2005). Dog attacks often kill a large portion of a flock at one time and are by far the most frequent cause of duck loss.[62]

The availability of favored varieties of domestic ducks is limited on each island. Farmers need to have access to a source of replacement ducks in order to maintain a steady flock to support consistent snail suppression.

There is some concern among wildlife biologists in the state (USFWS and DOFAW) regarding potential interactions between koloa (Hawaiian duck, *Anas wyvilliana*) and domestic ducks from the Mallard bloodline (*Anas platyrhynchos*), which encompasses almost all domestic duck breeds. In response to these concerns, taro farmers voluntarily developed, with the assistance of specialists, a guideline for the use of domestic ducks as snail control (see Appendix A). Taro farmers also report that in the 16 years that ducks have been actively used for apple snail control (since 1990) not one single incident of koloa contact/interaction with these controlled flocks has been observed.

The domestic duck use guideline provides information on selection, care, management and monitoring, disease control, and caging during non-lo'i periods. Ducks require protective cages during the evenings against dogs. This also eliminates any chance of mixing with koloa in wetland areas from dusk to dawn.[63] Ducks raised from hatchling stage take some attention and time; both young and adult ducks take readily to snail control. Juvenile ducks appear to be the biggest snail consumers.

In 2005, USDA Natural Resources Conservation Service staff developed a Practice for Shallow Water Management that would support domestic duck use as a means of apple snail

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[62] Every taro farmer using domestic ducks for apple snail control in Hawai'i has experienced the damage left by marauding dogs. The highest reported number of ducks killed at one time was 17 in the last several years; more than half the flock. Such attacks can set a farmer’s control program back six months to one year.

[63] Farmers observe that koloa appear to be most active during the periods from dusk to dawn when snail control ducks are already caged (Tanji, pers. com 2004).

control in taro patches that receive Farm Bill funding. NRCS began defining and testing this Practice that is eligible for cost-share assistance in late 2005 with farmers on the island of Hawai'i. The Practice includes the use of boundary fencing around lo'i kalo, ducks, and duck shelters in a managed setting as an acceptable pest management strategy for taro farming. No information is available yet as to the success of this program.

Currently, serious constraints to apple snail control exist for taro farmers in protected wetland areas. Both long-term fallow and the use of domestic ducks are not allowed in such places as Hanalei Refuge where apple snail populations are also the highest in the state. It is possible to produce a sterile duck (mullard) to negate a potential event of kolo/domestic duck pair-bonding; however, such birds have not been tested for their usability in taro patches, are not available currently in Hawai'i and are prohibited from entering the state due to avian flu and West Nile virus risks.

5.20 Combined methods

Farmers globally have proven to be the most astute and accurate source of insights for control measures and together they have found a suite of practices that have helped minimize snail damage. In Hawai'i these combinations differ from site to site. The most effective combination of practices observed during the development of this Plan appear to be those that take a complete and holistic approach which includes short and long-term fallow with cover crops, dry-downs, trenching, organic fertilizer compounds, and ducks. Where fallow, trenching, and hand-picking are the prevailing group of practices, snail levels do not appear as low as those systems using ducks as part of the suite of practices.

Problems with weeds are almost eliminated and dry-downs are only necessary once or twice a cycle when increased colder water flows are added to the equation (in combination with ducks, hand picking of larger snails and regular elimination of egg clusters).

The key to success is the fine tuning of the system, where control practices are matched to seasonal changes in the environment. For example, several farmers describe how applying intensive hand-picking or ducks to the period just prior to hibernation (September – November) means fewer snails and fewer reproducing adults surviving into the following spring. Using ducks to efficiently hit the beginning of population booms in March again reduces the number of mature snails in the lo'i. Vigilance is constant.

5.21 Outreach education

The Filipino community in Hawai'i has been identified as an important group to target for outreach education in regards to the apple snail because of their use of the snail in cultural foods and their association with its spread across the state. In 1994, the HDOA produced an educational flyer directed at the Filipino community, particularly those with access to open markets on each island. The brochure was bilingual (English and Ilicano). It had no measureable affect on consumers and retailers in this target group.

In the same year, a colored flyer with a harsher warning describing *Pomacea canaliculata* as an invasive species was distributed on all islands. Anecdotal observation suggests the image got people's attention, briefly, but again there was no visible increase in awareness or change in behavior by the group most closely associated with its spread.

The pest-for-profit program implemented by UH SEA GRANT (described above) created controversy and uncertainty over whether the snail was being promoted as cash crop or being controlled as a harmful pest. Confusion persisted with an HDOA website which described apple snails as an economic enterprise opportunity on one page and an invasive species on another.[64] A consistent message is required if outreach education is to gain support.

The multicultural communities that live in Hawai'i present a challenge from both a language and cultural perspective. For some groups, the concept of an invasive species is not understood; education must begin there. The Coordinating Group on Alien Pest Species has produced a series of PSAs that were shown on television beginning in 2006. More projects are spreading the word and educating students and communities about invasive species, however, information has yet to be translated into the many other languages present in Hawai'i, beyond English. Pre- and post-PSA surveys to determine message effectiveness do not typically seek out ESL communities for feedback.

Finding the appropriate venues and format for introducing information to each sector of the larger community is critically important. A written flyer is least likely to have an impact in a community that may not read a lot, communicates face-to-face, or where kinisetic (active, hands on) learning is the norm. Presentation, discussion and interaction at the individual level are key.

5.22 Enforcement

Inspection and enforcement of invasive species laws and rules have increased in recent years, as education, information and coordination between agencies has improved. No data was found on the level of inspection or enforcement specifically directed at apple snail control in Hawai'i. Not one single arrest for malicious dumping or deliberate introduction has occurred since its arrival in Hawai'i.

It is illegal to introduce apple snails into the wild in Hawai'i, to transport live snails on interstate highways or between islands, but without an enforcement officer on hand to observe the introduction or transport, it is almost impossible to make a case for arrest.

Part of enforcement is the need for laws and rules which clearly define what is acceptable. No standards exist for escape prevention in snail-raising facilities and regular inspection of these sites does not occur.

The aquatic pet industry has voluntarily removed *Pomacea canaliculata* from most, but not all stores in Hawai'i. Apple snails are occasionally observed for sale in Chinatown, Honolulu

[64] Apple snails were removed from the economic enterprise page in 2004 but remain listed as an available aquaculture product in the state.

and are typically sold, traded or shared live among informal markets and between families and friends. It is unclear in the laws that pertain to invasive species, if the sale of live snails (a recognized invasive species) from existing stock in the islands, whether for pets or as food, is illegal or not.

The effectiveness of outreach education may be increased by the use of enforcement as a deterrent, if resources exist to better support consistent inspection.

The dilemma that needs to be addressed within the taro farming community is the situation where a single farmer, land owner, or manager refuses to implement snail control measures and continues to be a source of apple snails that serve to re-infest adjacent farms and the surrounding landscape.

6. Apple snail impacts

It has been a misperception on the part of public and private agencies and organizations that because apple snails are confined to wetland and taro growing areas (a finite and limited acreage) that the potential impact of this species is not on the same level as such species as coqui frogs or miconia. A review of the stakeholders (pg. 13) illustrates how far reaching the threat to kalo in Hawai'i could be on a socio-economic level. Evidence indicates that apple snails far surpass *Salvinia* in statewide environmental impacts. Agricultural, economic, health and cultural impacts are only now becoming apparent. The consequences of this invasive pest to the very heart of cultural tradition and identity in Hawai'i are immeasurable.

6.1 Environmental impacts - streams, waterways, and lo'i kalo systems

As described in Section 4, apple snail distribution has reached most wet areas on the islands of Kaua'i, O'ahu, Maui, Lana'i, and Hawai'i. The minimum potential acreage at risk from this alien predator is estimated to be almost 11,000 acres, including most freshwater Core and Supporting wetlands listed in the USFWS recovery plan for Hawaiian waterbirds.

Severely diminished stream flows (volume) throughout Hawai'i have resulted in a lack of access to cooler, faster water flows for lo'i kalo. There is a direct relationship between this condition and the presence of magnified apple snail populations (as well as higher disease rates) in most taro growing areas.[65] The ability to maintain cooler water temperatures in taro patches is a condition of fully flowing streams connected to lo'i kalo systems. Cooler water temperatures are also a consistent condition of streams that have not been diverted. Where intermittent conditions exist; standing water and stagnant pools in lower stream reaches favor exotics and become a high risk for apple snail colonization, especially when considering that one of the primary means of dispersal is human (S. Hau, 2006 pers. com.).

Channelized, concreted streams with no shade also have higher water temperatures; prime habitat for alien invasives. From Waihe'e to Kahului, Maui, irrigation and drainage ditches support a habitual apple snail population.[66] One such ditch empties into Kanaha Pond, an important wetland for Hawaiian waterbird recovery (Ibid).

An unexpected potential impact related to the geological structure of the Hawaiian Islands is revealed by farmers' experiences with fallow. In some areas, snails continued to survive in

[65] Temperature has been shown to have a direct impact on apple snail maturation and egg laying (Cowie 2002). USGS surveys of changes in stream biotic health before and after the return of water to streams in Windward O'ahu clearly show that increased water flows result in immediate declines in alien, invasive aquatic water species (P. Achitoff, pers. com. 2006). Taro farms fed by undiverted streams exhibit consistently lower water temperatures.

[66] The lack of vegetation in most parts of the system inhibits egg laying to some degree but decomposing debris provides a plentiful food source. Snails readily lay eggs on lo'i banks and low grass if vegetation in the lo'i is unavailable.

dried patches for more than two years. At Wailua, Maui (near Kipahulu) attempts at fallow were not successful until almost three years had passed, even though lo'i were completely dry and no surface ponding occurred.[67] Farmers suggest that this is due to the existence of underground springs, ponds and water flows which are prevalent in the area (J. Lind, pers. com. 2006). Such underground water sources permeate the islands. Hawaiian legends are full of references to underground streams, pools and artesian caves. If the pest has reached such water sources, the endemic biota hidden there may be at risk. Apple snails are found in a number of ponds at one such site in Paukūkalo, Wailuku, Maui (privately owned) where artesian springs, ponds and wetlands are prevalent.[68]

Little information exists on the impact of apple snails to streams and freshwater wetlands. No studies have been conducted in Hawai'i to assess snail competition for food or space with native freshwater biota. Carlsson, Brönmark, and Hansson (2004) recently studied the habit of apple snails in Asian wetlands and found that they significantly alter ecosystem health and function. A survey of natural wetlands in Thailand revealed that high densities of this invasive snail were associated with almost complete absence of aquatic plants, high nutrient concentrations, and subsequent blooms in phytoplankton biomass. This change in ecosystem structure also compromised the integrity of valuable wetland functions and could "trigger a shift from clear water and macrophyte dominance to a turbid state dominated by planktonic algae." The implications for Hawai'i wetlands, ponds, springs and other slow waterbodies should be heeded. Unchecked wetland apple snail populations represent an ecological time bomb. Hawaii's AIS Plan calls for recognizing that "degraded habitats may facilitate the decline of native species and/or the proliferation of nonnative species (Strategy 4K)." The feasibility of control in such environments seems bleak but a limited number of strategies are available.

Wetlands have received little invasive species management in Hawai'i in the past; although there have been positive changes in the last few years. Where active management is occurring, work is focused primarily on non-native vegetation removal to improve endangered waterbird habitat but not on system level approaches that include apple snail control. Wetland managers throughout the state confirm that no apple snail specific controls are in place at most wetlands where the snail is found.[69] The result has been that these wetlands function as sinks from which re-infestation of taro lo'i in adjacent areas occurs. Recent flooding across the state in March 2006 illustrates this well. Taro farmers in Hanalei describe how water from federal wetlands fronting the valley backed up and redeposited snails that had been flushed down by waters running mauka to makai back into lo'i and 'auwai (irrigation channels) in great densities.[70] Taro farmers in Waipi'o, Hawai'i however,

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[67] These patches are in an isolated section of Maui with no possibility of recontamination from adjoining lo`i or `auwai. Termination of fallow after one year resulted in immediate return of apple snails (J. Lind, 2006).

[68] This site should be considered for research (with the permission of the landowner) to investigate the question of whether the snails are moving through underground pathways, including from off site.

[69] Pacific Coast Joint Venture Steering Committee meeting, East-West Center, Honolulu. May 5, 2005. Only one wetland manager (O'ahu) had implemented some measure of apple snail control through the use of salt-water flushing, a method appropriate only to brackish habitats.

[70] Water flows in Hanalei bay tend to get pushed back into the wetlands dependent on the tides and the seasons.

report that during floods in earlier years, water flows naturally broke through soil deposits and vegetation at the mouth of the valley and reached the ocean where they are swept away. The hydrologic dynamics of each site will impact the degree of environmental damage this snail is capable of inflicting.

Unmanaged snail populations are present in numerous natural wetlands, irrigation ditches and man-made ponds throughout the state, including Kawainui Marsh, Ka'elepulu Pond (Enchanted Lake; D. Smith, pers. com. 2006), Campbell National Wildlife Refuge,[71] and the UH Quarry Pond; the lower and mid-reaches of Waipi'o Valley, Hawai'i; the Hanalei Refuge, Kaua'i; parts of Ke'anae Peninsula and the irrigation ditch system that passes through Kahului town and empties into Kanaha Pond on Maui; and the golf course pond on Lana'i. It has been suggested that impoverished food sources, such as invertebrate organism populations, in at least some of the above wetlands (possibly due to altered habitats from high densities of apple snails) may cause endangered waterbirds to seek out taro plants as the next attractive food source.[72] In at least one case, this change in ecosystem dynamics caused significant damage to local taro farms.[73]

Koloa, 'alae 'ula'ula, 'auku'u and cattle egrets may feed on smaller apple snails (farmer observation) but to what degree is unknown. Tahitian and possibly Malaysian freshwater prawns, both alien species, include the apple snails in their diet (Levin, field notes 2004-2005). No interaction with 'o'opu or other native biota have been recorded. Of concern are impacts to endemic dragonflies and damselflies and 'o'opu in freshwater life stages from impoverished habitats. The risk of disease or host transmission from snails to other animals, including humans, may be high (see Health impacts).

6.2 Agricultural impacts

Pomacea canaliculata is an indiscriminate feeder. They have been documented and observed consuming weeds, ong choi and watercress, but the prevalence of the species in taro patches makes this the hardest hit crop. The number of commercial taro farms and acres in taro production over the last five years has significantly dropped from 430 to 350 acres and 185 to 110 farms; a 19 percent and 41 percent decline respectively. While no data is available on the reasons behind such losses, apple snails have likely played a role.

Apple snails have taken a toll on total crop production, accounting for an estimated 18 to 20 percent loss according to HDOA statistics (HASS 2004). A more recent survey of taro farmers suggests the loss in yields due to apple snails is slightly higher at 20 to 25 percent (Levin et al. 2005). The economic impacts of this change are discussed below in Section 5.3.

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[71] Managers at Campbell Refuge recently reported using salt water to control snails in some portions of the marsh, however, mitigation of infested water sources coming into the marsh is beyond the control of Refuge staff (M. Silbernagle, pers. com. 2006).

[72] A HARC study on organic snail control compounds found no aquatic organisms other than apple snails present in any test plots during Kaua'i field trials (M. Jackson, 2006, pers. com.).

[73] Crop damage by native birds were estimated at several hundred thousand dollars.

The presence of *Pomacea canaliculata* in the lo'i system has dramatically increased labor hours for farmers by almost 50 percent. In some cases, up to 40 percent of a farmer's time is devoted specifically to hand-picking apple snails. In an effort to control the snail, farmers have had to take on additional tasks such as raising and managing ducks, growing and managing cover crops, adapting water management regimes, and spending hundreds of hours per month hand collecting and disposing of snails. A consistent statement that reappeared many times in the development of this Plan was that taro farmers are tired. They want to go back to being "just taro farmers"; not duck farmers or snail farmers. This is not an idle statement reminiscing about a long ago past; it has only been 20 years since the snail reached critical mass and became a serious threat to crop survival.

Figure 6. Apple Snail Impacts to Environmental, Labor, Time and Cash Aspects of Growing Kalo, describes these changes to agricultural practice further. For those farmers without access to ducks to manage the snails, control methods result in an increase of weeds in the system and a subsequent decline in corm size and quality. This translates to an increase in the number of corms needed to fill the typical 80lb bag sent to millers. The higher frequency of disturbance in the lo'i to control snails and weeds escalates the chance of disease occurrences such as *phytophthera* and pocket rot.[74]

Farmers also experience clogged irrigation pipes from apple snails in the same manner that Asiatic clams have caused damage to irrigation systems. The cost of mitigation includes the establishment of screens and bags and constant monitoring to prevent build-up.

Farmers in Hanalei, Kaua'i, and the entire industry, experience more severe crop losses from the snail because of the constraints placed on control methods within the Hanalei Wildlife Refuge due to the presence of protected bird species. A total of 209 acres in taro cultivation on Kaua'i fall under restrictions that prevent the use of long-term fallow or domestic ducks, the two most effective and efficient control mechanisms currently available.[75] This represents 41% of all taro-growing lands in the state and 89% of the estimated 235 acres in commercial production on Kaua'i. Consumers throughout the state face higher poi costs when Hanalei farms have shortages; the impacts are felt most strongly on O'ahu.

Threats to taro genetic diversity

Lo'i kalo are planted using the young offshoots (keiki) from mature plants and taro tops after harvesting the corm. Taro farmers save these propagules and prepare them for replanting as huli. In this manner, kalo has been perpetuated since its arrival with Polynesians in the islands to the present day. The plant is essentially a clone of its parent each time it is returned to the mud. As many as 300-400 taro cultivars may have been developed by Hawaiians over many centuries of which an estimated 69 remain.[76] Varieties were associated

[74] HASS reports these diseases as the other major cause of annual declines in yield in the taro industry (2004).

[75] USFWS 2005; total acreage recommended as Core and Supporting wetlands for protected freshwater birds.

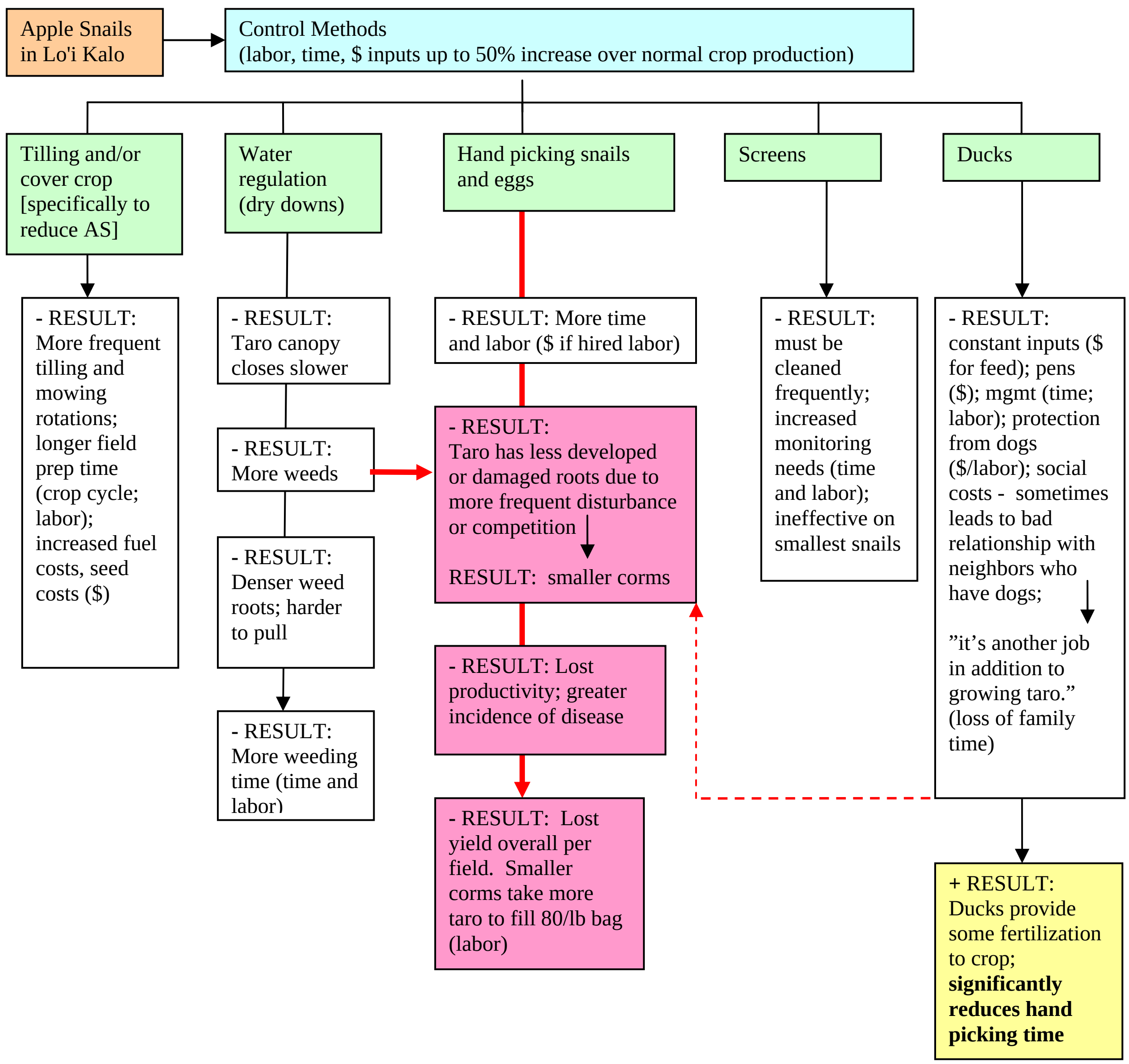
[76] Whitney et al (1939) describes a total of 84 varieties of which 69 are known to be native Hawaiian in origin.

specifically with different islands and ahupua'a, soil, climate and flooding conditions. Today, a limited number of those Hawaiian cultivars are still preferred by poi millers. As farmers struggle to maintain their livelihoods, they are reaching back to this traditional resource to find disease resistance, strengthen and diversify their crop.

Taro farmers do not buy and sell huli, but rather, save propagules from a harvest to replant their own fields, as well as to share and exchange with other farmers. This is an important part of the traditional cultural practices surrounding taro farming (see Cultural Impacts below).[77] Snails take a heavy toll on both the number of keiki that make it to harvest and the survival of newly planted huli. Farmers on every island report a shortage of taro propagules, partially attributed to apple snails. They also report regular replacement of huli in the early stages of crop growth; losses of planting material as high as 80-90 percent have been documented (SARE 2004). This one aspect of apple snail impacts represents the biggest threat to the continued survival of traditional taro varieties and taro genetic diversity and the ability of farmers to return the varieties to their rightful place in wetland cultivation.

[77] Agricultural sciences defines "culture" as an agronomic or "cultivation" practice. In this document, "culture" refers to traditional Hawaiian culture, and while a cultural practice may also be an agricultural practice, it is a much more complex activity when understood within the larger context of a whole way of life.

FIG.2. APPLE SNAIL IMPACTS TO THE ENVIRONMENTAL, LABOR, TIME AND CASH ASPECTS OF GROWING KALO[78]



[78] Cash is distinguished from labor and time as a separate resource. Farmers may have access to additional labor/time but actual cash dollars may be more scarce.

6.3 Ecomomic impacts

The Innovations Report (a web report out of Lund University, Germany) estimates that "in the Philippines alone, accumulative crop losses since the snail introduction is estimated to 1 billion US dollars" (www.innovations-report.com).

In 2005, National Agricultural Statistics Service (http://www.nass.usda.gov/hi/) reported the farm value of taro production at 4 million pounds (down 19 percent from 2004). Kaua'i alone, accounts for 2.9 million pounds (72.5 percent) of all taro produced in the state. The farm value of all taro products was $2.2 million (down 23 percent). Hawai'i County taro revenues declined by 51 percent between 2005 and 2004. Approximately 3.9 million pounds of poi were produced in Hawai'i in 2005 (down 24 percent); the lowest totals since NASS began documenting taro statistics in 1946. Farmers receive an average $1,075 - $1,250 per U.S. ton (data from farmer interviews; August 2005 prices). They report that apple snails can consume the labor of an entire year in a single week when snail densities outpace the farmers' ability to limit population impacts.

Compared to other agricultural crops in the state, taro *appears* to be a minor producer (just over 1 percent of all crop lands) – only if the assessment stops at the superficial counting of acreage, yields and market values. The direct and indirect socio-economic impacts from this pest are far reaching. A study entitled the *Economic Impact of Apple Snails on Taro Culture in Hawai'i* (2004-2006) quantified some of the economic impacts specific to taro farmers and their families.[79] The study finds that taro cultivation is under threat economically, ecologically and culturally due, in large part, to the apple snail *Pomacea canaliculata*. As reported above, at least two-thirds of all lo'i kalo lands (wetland taro systems) may be infested with the snail. Crop loss estimates among farmers surveyed range from 18-25% annually despite constant control efforts. Pest mitigation has increased labor, time, and cash inputs collectively by as much as 50 percent above traditional production costs; hand labor can reach as high as 40 percent of additional costs. Apple snail control costs in Hanalei, particularly labor hours for hand-picking during the summer months, are the highest in the islands. Limitations on apple snail control methods to 89 percent of commercial taro acreage on Kaua'i have created undue economic and physical hardship for farmers on that island and to the survival of the taro industry as a whole.

The study also reveals that economic impacts to families who rely on this crop for food are high. Families who grow kalo for home consumption and depend on it as a consistent portion of their diet are at risk of doubling food budget needs (cash outputs) without access to this traditional food source. Average monthly consumption of poi per family was estimated at 21 pounds, taro at almost 9 pounds, and lū'au leaf at approximately 7.5 pounds. Farmer estimated household food budgets were an average $297 per month. At retail prices, the cost for taro, poi and leaf at the nearest store was an estimated $137 per month. Replacement costs represented a low of 18 percent and a high of 150 percent increase in total food budget

[79] USDA T-STAR Grant through UH CTAHR (R. Cowie, C. Ferguson, and P. Levin with K. Burnett, K. Hayes and J. Taylor).

needs per family, excluding travel time and gas costs[80] (see Section 5.4 for further considerations of this issue related to health). A weighted average of 64 percent more cash per month per family was needed to make up for potential food losses.

An additional 165 pounds of taro are given away on average to the wider community or exchanged for labor most months on each farm; a charitable contribution by farmers equal to a retail value of $577 to almost $1,000 per month. Local fundraisers, graduations, baby parties and other community events benefit from this. One taro farm whose purpose is to educate and benefit the community, reported that "for every two bags we harvest, we give one away". A loss of these gifts to the community could seriously curtail local fundraising outcomes and increase the costs of local celebrations dramatically.

Income lost from apple snails impacts the future for taro farming families, in particular the ability to send children to college, care for grandparents or assist in raising grandchildren.

Funding for snail control

It is may not be possible to account for all dollars spent by the State of Hawai'i and other agencies towards apple snail control. It is also difficult to trace and sort out the overlap between legislative allocations to agencies and subsequent projects. Table 5 below, provides information on all the documented sources of funding for pest control that could be found since the control efforts were initiated with the Department of Agriculture. It is highly likely that the total amount of funding spent on this invasive species is less than reported in the Table 5, due to the difficulty of distinguishing where legislative funds were allocated.

If the numbers below are correct, an estimated $378,617 may have been spent on apple snail controls in the last 16 years; $135,000 on a pest-for-profit program (39 percent of all funding, excluding monies for the economic impact study and control plan development). Between 1996 and 2002 no funding appears to have been spent on apple snail control.

By contrast, an intensive approach applied when alien species populations are still contained within a limited range saves millions of dollars in future control efforts. *Salvinia molesta* might be considered as a case. *Salvinia* existed in small populations in Lake Wilson and a limited number of additional sites for more than a decade. When the water weed expanded to the entire surface of the lake serious action was taken. Almost a million dollars was spent on the cleanup of this water weed on a single location in a single year, with the assistance of hundreds of people.

[80] Overall food budgets are low due to the availability of fresh vegetables, fruits, fish and game meat for many taro growing families. Without these additional resources many households would be unable to afford the degree of healthy foods found at their tables. Frequency of trips to the nearest store ranged from every few days to twice per month. Roundtrip mileage ranged from under two miles to more than 40.

Table 5. Apple snail actions and funding by project and year

Action and funding source	Implementing Agent	Year funded	Total $
COPPER SULFATE			
Copper sulfate trials – HI legislature[81]	HDOA	1992-1995	@$100,000?
USDA and State of Hawai'i[82]		1996	$2,333
ORGANIC COMPOUNDS			
Chemoattractive bait potential[83]	Maryland Cooperative Fish and Wildlife Research Unit	1996	$5,000
Papaya and neem extract trials - State of Hawai'i [84]	HARC	2002	$10,780
State of Hawai'i	HARC	2003	$12,068
SARE (plus match)[85]	HARC	2004	$31,831 ($6,750)
PEST-FOR-PROFIT			
Pest-for-Profit program[86] – State of Hawai'`i, DHHL feasibility study $10K, DLNR provided summer intern, Small Business Innovation Research Grant $70K	UH SEA GRANT	2002-2004	$80,000
Integrated Snail Production – part of the SBIR grant[87]	NFS/Boke Farms	1994	$55,605
DUCKS			
Vacuum and Duck control trials, Maui – OHA $20K, Maui County Office of Economic Development $15K; Alu Like provided 4 workers	Tri-Isle RC&D Maui	1993	$35,000
Duck control trial, O'ahu[88]. - OHA $15,000			$15,000
OTHER			
Economic impacts study; distribution mapping – USDA T-STAR grant	UH CTAHR	2005	@$21,000
Statewide control plan – DLNR Division of Aquatics	E kūpaku ka 'āina for 'Onipa'a Nā Hui Kalo	2005	$10,000
TOTAL FUNDING 1989-2005 [16 years]		**Federal**	**$21,000**
		State	**$322,617**
		Other	**$35,000**
		ALL	**$378,617**

[81] HDOA.
[82] Ibid.
[83] Ibid.
[84] HDOA Report to the Twenty-First Legislature, 2002 Regular Session (January 2002); and Report to the Twenty-Second Legislature, 2003 Regular Session (January 2003).

[85] SARE Reporting System: SW03-010: Project Overview. Final Report 2004.

[86] Estimates provided by Tarmaru, (pers. com. 2005)

[87] SBA SBIR report 1994 (http://www.sba.gov/gopher/Innovation-And-Research/Awd94/awdhi.txt)

[88] HDOA.

The all-out approach for Lake Wilson appears to have worked for the immediate future; as long as regular monitoring and rapid response for small reoccurring populations are maintained. Had *Salvinia* spread to additional sites (ie. wetlands across the state) the costs of control would have multiplied accordingly. Eliminating the weed at the point of initial observation in the wild would have significantly reduced costs to the state.[89] The high cost of the budget estimated for apple snail control efforts (Section 9. Resource Needs) is a reflection of a failure to allocate sufficient resources at the earliest possible opportunity. The current situation is the equivalent of five or six Lake Wilsons.

The clear trend with apple snail control projects was that when it was over it was over. After funding ended, each one shut down. Most farmers didn't pursue continued use of these program- designed practices.

There is little faith among farmers that they can do all the work necessary to control the snail on their own, particularly those things that need to be addressed at a landscape level and that require landowner and agency action.

6.4 Health impacts

Disease risks

Apple snails are a known vector for disease transfer between rats and humans, particularly rat lungworm (*Angiostrongylus cantonensis)*, a primary cause of *eosinophilic meningitis*. The nematode has been documented as present in rats in Hawai'i since the 1960s. Data from the State Department of Health Vector Control indicates *A. cantonensis* in rats has been in overall decline for the last 15 years, however 1990 and 1995 were years of high incidence (Wes Warashina, pers. com. 2004). Humans can become infected by ingestion of freshwater and terrestrial snails and slugs, vegetables, or transport hosts such as freshwater prawns, crayfish, shrimp, crabs, frogs, fish, and planarians (flatworms) (Hung-Chin Tsai *et al*. 2004; A. Buchholz, pers. com. 2006) or contact with these organisms through an open wound or mucus membranes (eyes, nose, mouth).

In Taiwan and Korea, African and apple snails are the major intermediate host for rat lungworm. Taiwan recorded hundreds of cases of *eosinophilic meningitis* in the 1970s; most of the episodes occurring in children who had eaten or played with snails. More recent cases were caused by consumption of raw snails and vegetable juice health drinks (Hung-Chin Tsai *et al*. 2004). The Hawai'i Department of Health Disease Outbreak Control Division recorded six cases of *eosinophilic meningitis* in the state in 2005 associated with slugs and snails in unwashed vegetable greens (Altonn 2005). Prior to 2005, health professionals were not required to report the occurrence of *Angiostongyliasis* (rat lungworm) or *eosinophilic*

[89] The cost of port of entry prevention is unknown, but can be ameliorated over hundreds of species prevented from entering the state annually. If a dozen "salvinia's" are prevented from establishing each year, potentially millions of dollars in cleanup costs are saved. The chance of entry to the state for many potentially invasive species is further reduced by placing such species on a "not permitted" list as they become suspected or known invasives in other parts of the world; a measure which costs no additional dollars.

meningitis in patients to state health agencies; at the time of this writing there was no available information on whether the disease has crossed from apple snails to humans, or apple snails to freshwater prawns to humans (a concern at sites where prawns feed on apple snails) in Hawai'i.

Field studies in southern Taiwan have shown that 14–31% of [*Pomacea canaliculata*] contain third-stage larvae of *A. cantonensis* (Hung-Chin Tsai *et al*. 2004). The DOH currently conducts no field testing of apple snails. Such testing would require specialized research not available through the DOH at this time (A. Buchholz, per.com. 2006). Apple snails (at least three of the four species present in Hawai'i) are consumed and sold as food in restaurants,[90] open markets and grocery stores in the islands, particularly among the Filipino community.

The presence of rats in and around lo'i kalo is common. Evidence of rat and mongoose predation on live snails has been observed at numerous sites, often during dry down phases when mud is exposed (Levin, field notes 2004-2005).[91] Snails removed from the lo'i are typically composted away from the patches but also serve as a food source for rodents and an attractant to other snails and slugs.

Hawai'i has one of the highest rates of *leptospirosis* in the nation. The disease is caused by contaminated water sources (through the urine of infected animals) coming in contact with an open wound or mucus membranes. Rats are the most common carriers of the bacteria (Chen 2002). Cases are more frequent in wetter districts of the islands, where most lo'i kalo are found. From 1975 to 1981, twenty confirmed cases of the disease were associated with taro farming in Hawai'i. Sixty percent of taro farmers tested for antibodies during the study showed positive results indicating they had been infected by *leptospirosis* at some time in their lives and 24 percent of this group had a confirmed history of the disease (Anderson et al. 1982; Reppun, pers. com. 2006). At the time of the study, rodents and mongoose were the primary carriers for all islands. In Maui, rats showed no infections, while as high as 25 percent of mongoose carried the pathogen. It is important to note that the apple snail *Pomacea canaliculata* did not arrive in taro patches until several years later. From 1999 through 2004, 11 confirmed cases of *leptospirosis* were documented among taro farmers (A. Buchholz, pers. com. 2006).

Apple snails increase the opportunity for *leptospirosis* vectors among the taro farming community, and any visitor to a taro patch, through two pathways: snails encourage the presence of rats (and rat urine) in or near water that flows through lo'i kalo, and snails increase the frequency of cuts from shells for those who work in or visit the lo'i. Until recently, the traditional taro farmer worked barefoot in the lo'i. Many farmers in apple snail infested districts now wear boots or tabis and require visitors to do so as well; cuts on the hands are still frequent. Farmers report cuts occur every week and may take up to one week to heal but most do not abstain from working during that time. An average of 32 work days per year are reported lost due to cuts from apple snails.[92]

[90] This includes several prominent chefs who have featured the snail on their menus in collaboration with the UH SEA GRANT pest-for-profit project.

[91] Mongoose is not documented as present on Kaua'i despite several reported sitings in the last few years.

[92] USDA T-STAR Grant - UH CTAHR *Economic Impacts of Apple Snails on Taro Culture in Hawai'i* study.

Family health and Hawaiian health

The economic study showed that many taro-growing families depend on the cultivation of taro for a significant portion of their dietary needs and that for these families, food budget needs (cash dollars) more than doubled (64 percent) without access to this resource. An average of 16 meals per month, or 17 percent of all meals, include kalo, poi or lū'au among taro farming families interviewed during the economic impact study. Loss of this resource due to apple snails (or any other cause) for these families is a health and welfare issue.

Health studies in the 1990's demonstrated that a diet strong in traditional Hawaiian foods, including kalo, leads to significant weight loss and improved heart, blood pressure and diabetes conditions over a relatively short period of time and is a successful intervention for such chronic diseases (Hughes, 1998; Shintani and Hughes, 1993; Shintani et al, 1991). In these studies, the principal starchy foods in the diet were taro and poi (along with sweet potatoes, yams, and breadfruit). As described above, the retail cost of taro, poi and lū'au make adherence to a healthy Hawaiian diet prohibitive for many. Students at Kanu o ka 'Āina New Century Public Charter School in Waimea, Hawai'i estimated in a math study project that to keep poi on the table of a family at every meal for a year would cost approximately $7,000-$8,000; a complete Hawaiian diet, about $15,000 annually (N. Kahakalau, pers. com. 2005). For families with minimal (or without) medical insurance and limited cash resources, a healthy diet becomes doubly important to long term fitness and minimizing future medical expenses.

The 3.9 million pounds of poi produced in 2005 are estimated to contribute to upwards of 15.6 million meals (at four servings per pound) on tables in Hawai'i. If all poi went to household meals, at the above average rate of 16 meals per month and assuming a family of five (1.25 lbs per meal; 240lbs per year), this could represent as many as 16,250 families able to maintain the steady presence of taro in their diets annually.[93] If this resource became unavailable, potential repercussions to the physical wellbeing of the thousands of non-farming families that consume poi on a regular basis and subsequent impacts to the state's health care system as a result of this loss, could be significant.

Food security in the home is also a homelands security issue of self-sufficiency within the state. As the only "ocean-locked" state in the nation, the loss of a staple as important as kalo, should be of concern at a local and a federal level.

Physically, apple snails have increased labor inputs tremendously (by almost 50 percent). The physical stress on the body of bending down to hand gather snails is similar to that of planting rice. Taro farmers are humble individuals. No farmer complained of physical problems from snail control efforts, but many talked about physical exhaustion and the loss of time that they would normally have spent with their families. Farmers faced with the heaviest infestations expressed mental exhaustion for a road that appears to have no end and an invasive species that seems to have no solutions. The question of how long farmers can continue to fight this pest without facing collapse is very real.

[93] Not all poi is used for household consumption. The amount of poi that is used by the hotel industry for lū'au shows, by restaurants or in value added products such as pies and breads is unknown.

The Hawaiian concept of 'ohana (family) encompasses kūpuna (grandparents), makua (parents), kamali'i (children) and mo'opuna (grandchildren), along with aunties, uncles, and cousins. The loss of income and food due to apple snails directly impacts the ability of farmers to care for their immediate family and their extended 'ohana. While it would not sever the connections, it would limit the resources available to tend to family wellbeing.

Endangered waterbird health

Botulism (*Clostridium botulinum*) outbreaks have occurred with some frequency over the last decade in several large wetlands in the state, including Kanaha and Ke'alia Ponds on Maui, and at least one site on Moloka'i, with subsequent losses of shorebirds and endangered waterbirds (Dibben-Young, pers, com.2005; Honolulu Star Bulletin, 2001; USFWS 2000, Scott 2000). A small freshwater pond outbreak occurred on Kaua'i in 2004 (taro farmer observation).

The World Health organization (2002) provides the following information on the development of the toxin formed by this bacteria: "The sporulated form of the bacterium is commonly found in soils, aquatic sediments and fish. The spores are heat-resistant. Under anaerobic conditions, botulinum spores can germinate, and the bacterium grow and produce the toxin." Once ingested, the toxin can result in rapid paralysis and death.

While there is no evidence at this time that the decaying apple snail bodies might provide a site for colonization by *Clostridium botulinum*, the presence of large masses of apple snails in the aquatic setting and anaerobic conditions often present in a taro patch or wetland may represent a very real opportunity for botulism outbreak, particularly in areas with limited water circulation.

The increased presence of rats and mongoose attracted to snail populations increases the vulnerability of the eggs and young of endangered waterbirds.

6.5 Educational impacts

There are 27 charter schools, 255 public schools, and 137 private schools in Hawai'i, with more than 229,000 students enrolled in 2005 (HDOE 2005; Heritage Foundation 2005). Taro lo'i throughout the state have become outdoor classrooms for teachers in public, private, and alternative schools, and for adult education programs. Thousands of students visit taro patches every year. The value of access to these sites and resources for teachers and students has not been calculated.

In 2004, a limited number of farmers surveyed reported approximately 9,425 visitors to their taro patches; primarily students, teachers, researchers and CTAHR extension agents. In many rural communities, teachers at local schools rely on taro farmers to host at least one field trip per class per year as part of science, natural environment, and Hawaiian culture curriculum. An average of 500 educational opportunities per farm per year were created by this goodwill on the part of taro farmers.[94] Based on anecdotal information from a variety of sources, the number of students and teachers who benefit from an association with a taro farm may be as high as 50,000 or more per year. Several farmers reported requiring students to wear boots or tabis in the lo'i since the arrival of apple snails, sometimes footing the bill for this themselves. Others report cancelled trips based on the health risks posed by the snail's presence as a vector for *leptospirosis*.

At least six charter schools focus heavily on culture-based learning.[95] Students and teachers at charter and immersion schools with a strong focus on Hawaiian culture regularly investigate a variety of topics in the context of the lo'i system, including natural sciences, ethnobotany, hydrology, ecology, math, language (both Hawaiian and English), cultural traditions, history and political science. Kanu o ka 'Āina New Century Public Charter School in Waimea, Hawai'i has a "campus" in Waipi'o in collaboration with a taro farming family in the valley. Students in younger grades at the Department of Education immersion school, Kula Kaiapuni 'o Ānuenue (O'ahu) spend at least one class per week in the lo'i. In both cases, students also gain the benefit of kalo in school meals or at special events.

At the University of Hawai'i, Mānoa at least seven undergraduate classes in the Hawaiian Studies and Botany departments benefit from or take place in the outdoor setting of the University's taro patch, including two courses specifically focused on taro farming. At Hawai'i Pacific University, at least one or two anthropology classes each year participate in field trips to taro farms during the semester.

Cultural learning centers such as Ka'ala Farms in Wai'anae, O'ahu play an important role in assisting hundreds of at-risk children and adults to gain useful skills and confidence in themselves. Teachers at Nānākuli and Wai'anae elementary, middle and high schools are regular users and beneficiaries of the resources at the farm, of which lo'i kalo are an integral part. Drug rehabilitation programs such as Ho'omau Ke Ola, which had 133 participants in 2003, are able to use lo'i kalo at Ka'ala Farms as one of the tools in the recovery process.

The Queen Lili'uokalani Children's Center, a social service agency created to support orphaned and destitute children in Hawai'i, particularly those of Hawaiian ancestry, has connected its beneficiaries to the taro farming community for more than a decade as part of a program of increasing social capacity by rebuilding families and communities together. QLCC, in partnership with 'Onipa'a Nā Hui Kalo, provides important, culturally-based opportunities for individual and community growth every year through the restoration of ancient lo'i kalo on each island. In 2004, QLCC served more than 6,000 youth directly and almost 29,000 children indirectly through its community organizing services (QLCC 2004).

If apple snails were to wipe out taro cultivation in Hawai'i, it would take with it all of the above described opportunities for learning and building individual, family and community

[94] Only 20 farmers provided numbers for this estimate; many farmers report field trips by schools but don't keep track of how many visit. The number of students and teachers who participate in field trips to taro patches from K-12 and beyond likely encompasses most students and schools in the state.

[95] State of Hawai'i Department of Education at http://165.248.6.166/data/schoollist_pcs.asp

capability. In addition, the children of taro farmers could find college financially out of reach. There is no data on the number of families whose children's higher education opportunities might be at risk; at minimum it would include taro farming families and their laborers, millers, and distributors.

6.6 Cultural impacts

Kalo is a central icon in many aspects of Hawaiian culture. In the ancient context, kalo is the elder brother, Hāloa, of the Hawaiian people. It connects the realm of the gods, to that of man, and to the land itself. In the modern context, the plant maintains importance and relevance within Hawaiian culture on many levels, including the symbolic representation of the 'ohana. The *Guidelines for Grassroots Lo'i Kalo Rehabilitation* (2003) writes:

> Genealogies connect us, one to the other. The story of Hāloa reminds us of our relationship to the earth and the gods. Wākea (the male – god of light and the heavens) and Papa (the female – goddess of the earth)…are referred to as the ancestors of the Hawaiian people. It is from Wakea and his daughter by Papa, Ho'ohōkūkalani, that the kalo plant comes. Their first child was stillborn. From the spot where the misformed body was buried grew a kalo plant. A second child was born and lives. Wākea names him after the firstborn, calling him Hāloa [the long stalk; the far reaching breath]. It is from Hāloa that the Hawaiian people descend. The older brother, in the form of kalo, feeds the younger brother. Kalo became the staple food for many generations of Hawaiians. This sacred connection is renewed each time kalo, lū'au or poi is eaten. ('Onipa'a Nā Hui Kalo 2003: 2)

The spirtitual leg of Hawaiian health includes wellbeing not just for the individual and the family but extends to Hāloa as older brother. The ability of farmers to care for Hawaiian taro varieties and for the taro-growing lands of each island, as well as their families and the communities who depend on this source of food, is an integral part of caring for Hāloa. The kuleana (responsibility of stewardship) of the mahi'ai kalo (taro farmer) to perpetuate kalo on the land has been jeopardized by the apple snail. The consistent loss of huli resources (the parent plants) and of huli themselves takes a toll on each successive generation of plants, on the acreage that can be farmed, the number of farmers who can maintain a source of huli to share with new generations of planters and on the number of families who will have poi at their table.

The possibility that kalo could be lost to apple snail pressures is one that places many taro farmers at a loss for words. The scenario evokes consistent responses that they would lose "everything"; their identity, culture, livelihood, connection to their family's history as taro farmers and the history of the places they live, as well as a place to teach local youth and future generations. "There is nothing we could go back to that would replace this. You can't explain it to someone who is only income oriented." For many farmers, taro is "in every conversation we have." Growing kalo is often viewed as a subsistence (limited) income activity for all but a small number of commercial farms; from the perspective of taro farmers and the communities they support, it is one of sustenance and abundance.

Taro farmers describe the cultural implications of the scenario this way: “We would lose taro in all its ramifications; kalo singularly defines Hawaiian culture as distinct from [other] Polynesian culture[s].” “Every time you work with the huli it’s a direct connection all the way back to the first Hawaiians; that's irreplaceable.” Taro resides at the piko (center) of Hawaiian culture.

The snail has fostered other more subtle disconnections between the farmer and the land, including one seemingly small aspect of taro farming, the tradition of working in bare feet in the lo'i mud. Bare feet are part of the reason why taro farmers have such a sense of connection to the land. A farmer’s feet and legs are like the hands of a lomilomi (Hawaiian massage) practitioner. With them, he/she senses the conditions of the soil, the depth and firmness of the mud, the temperature and circulation of water. The heath issues associated with the presence of apple snails have forced farmers to wear heavy rubber boots and tabis as a safety measure and severed this vital flow of energy and information between the 'āina and the soles of the feet.

One farmer summed up the impact of the snail; “Apple Snails are changing our way of life on a daily basis. If taro goes, part of the culture is lost. If it were to disappear, all the things it gives us, teaches us are gone - lost chances to experience it. If the door to taro closes, there is no other door to open."

7. RECOMMENDATIONS

It is clear from the above information, that the lack of consistent attention and resources for control of *Pomacea canaliculata* over the last 25 years has cost taro farmers in the state dearly. Taro farmers have long felt that the front line of apple snail control has been up to them. Because taro is considered to be a minor crop economically, and, because the snail has been perceived solely as an agricultural pest, even as it makes its way into wetlands across the state, it has left them standing alone. The day may come when looking into Waipi'o or Hanalei or Keana'e, taro will no longer be visible. With 50 percent increases in the labor and time directed towards snail control, very little leeway remains for farmers to continue. It is critical that the wealth of energy, networks and resources that exist in the state – individual, public, private, and non-profit - become part of the solution to preserving the beauty and abundance of gifts that kalo brings to Hawai'i and protecting critical wetlands before they are lost to this pest.

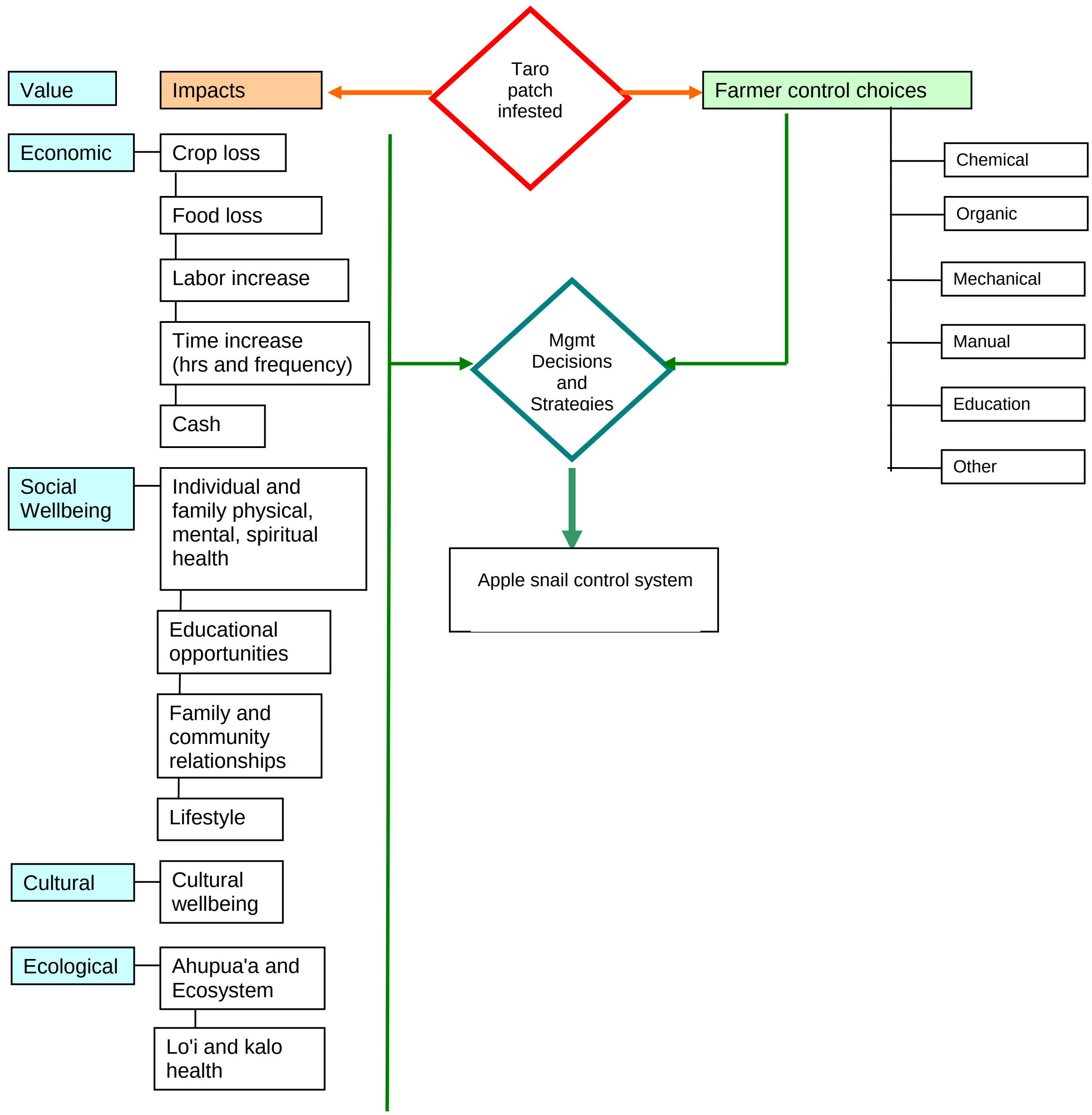
The recommendations that follow have been provided and carefully considered by dozens of taro farmers on five islands over the past ten months. These recommendations address immediate and long term issues related to the apple snail. They are as holistic and strategic in their composition as existing information and experience makes possible and require a holistic and strategic response; less than that would be to invite failure.

Decision-making

No one else spends more time in the fields or so many hours thinking about how to survive the snails to the next harvest than taro farmers, themselves. In order for agencies and researchers to provide the best support in the most useful form, it is important to understand what kind of things a taro farmer weighs in making decisions and selecting snail control techniques. This is clearly different than agency decision-making and one of the reasons why resource supports have fallen short of real needs. Funding decisions which continue to be based on the perception that kalo is a “minor crop” or that apple snails affect “limited acreage” lose sight of the importance of taro farming to the state and fail to understand the broad threat to Hawaii’s waterways.

The diagram below (Fig 3) was developed from information gathered during the economic impacts study. A variety of factors are considered, many of which fall outside the realm of conventional economics, such as lifestyle choices, cultural continuity, and environmental health. Taro farmers are typically “cash-poor” and invest significant amounts of time and labor into bringing a crop to harvest, and to managing the lo'i kalo. A control technique that requires large amounts of additional time/labor is not a realistic option under such conditions. Some taro farmers are also organic and do not support the use of chemical solutions without serious analysis of long-term environmental impacts.

Fig. 3. Weighing apple snail control decisions in the real world of taro farming



An ahupua'a approach

Farmers, researchers, and agencies wish there was a magic bullet for this pest. Experience throughout the world has found that a multi-faceted, carefully monitored and adjusted systems approach can, at least, reduce populations on-farm to manageable concentrations. But, that does not account for lands beyond the edge of the farm. At one level, Hawaii's experience mimics that of other countries. At another level, taro farmers have been exceedingly perceptive about the subtle behaviors of this pest not just in the lo'i, but within the larger landscape. This is perhaps due to a deep-rooted ahupua'a-based thinking that is unavoidable if you are a taro farmer.

In the traditional Hawaiian context, lo'i kalo functioned as part of a much broader ecosystem – the ahupua'a. This ancient land division evolved out of an understanding of how resources were supported by and connected to each other in the islands and the surrounding ocean. Traditional ahupua'a were politically and ecologically designated lands, whose boundaries were outlined by natural features of the landscape – from ridge to ridge, from the sea to the mountains.[96] Within this context, wai (water) was the source of wealth (waiwai). A mahi'ai kalo (taro farmer) had to be aware of the connections of water; from the patterns of the mists and rains at the top of the ahupua'a to the tides and currents as the streams entered the ocean. All affected his lo'i. He also had to be aware of the weather, winds, topography, soils, flora and fauna, seasons, and moons; and the behavior of things in relation to each other.

Conditions at the source of the water and in the stream coming into the lo'i, affected the health of the taro, its productivity, the quality of its growth. How a farmer cared, in turn, for his patches affected everything downstream. His dependence on the resources in the ocean, down to the quality of the salt that seasoned his lū'au (taro leaf soup), increased his responsibilities to the land.

Taro farmers today still work within this context despite the fact that many ahupua'a level functions have been interrupted or disconnected, particularly the water systems on which the health of these traditionally designated districts depend. Their understanding of this interdependency with the streams and the reef makes them mindful of what goes into and comes out of the lo'i. They are often involved in watershed and coastal zone protection for the same reason. They question the use of chemicals such as copper sulfate because they worry about the long term impacts it may have on the whole system. And, they share information and resources with each other, because that is how things get done.

Within the recommendations below you will see this ahupua'a manner of thinking emerge. Kenji (2004) suggests it is at this landscape level that apple snail control work has yet to be done.

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[96] Not all ahupua'a were so clearly distinguished. Most but not all, contained the resources necessary to survive within them, including a source of freshwater, a range of forested uplands, lands to produce food, and access to the ocean and nearshore fisheries.

7.1 Pro-active prevention

Pro-active prevention includes two key facets; keeping snails out of areas that currently remain snail-free, and protection and preservation of traditional Hawaiian taro varieties, secure huli resources, cultural practice, and lifestyle choices from loss due to the snails.

A. Protecting snail-free districts

The largest snail-free district in the state is the island of Moloka"i. This island should be designated as a protected zone with the highest levels of quarantine. Other traditional taro districts where snails are not yet present, or have been eradicated include, Kīpahulu, Wailua and Ukumehame, along with the Nuu wetlands in Maui; Wai'anae, upper Waiāhole, Kahana and possibly Waimea, O'ahu; portions of the west side of Kaua'i; and the Keokaha and Puna coastal areas, Hawai'i (refer to the distribution maps for a complete picture of unaffected watersheds). The AIS Plan calls for implementation of a coordinated system for rapid response efforts to contain newly detected AIS (Strategy 4A). This should also address those areas not yet exposed to existing pest species.

In general

<u>'Onipa'a Nā Hui Kalo and other taro associations</u>

1. A snail infestation prevention protocol should be developed and distributed to all taro farmers in the Hui, as well as made available to any other taro planters, students, teachers, agencies and community members. Use of this protocol should be mandatory for all 'Onipa'a, and QLCC events.

2. An information pamphlet about the snail and prevention strategies should be developed by the Hui and distributed through QLCC, DLNR-Division of Aquatic Resources, Department of Health, OHA and other cultural and community-based organizations. A version of the information sheet and prevention protocol should be added to the CGAPS - ISCs webpage.

3. For at least the next five years, educational booths at taro festivals on each island should focus on and provide information about apple snails and apple snail control.

<u>Individual action – taro farmers</u>

1. Any taro farmer traveling from an infested area to a snail-free area should clean all mud from and disinfect boots, shoes, tools and vehicles (including tires) carefully.

2. Do not transport or share huli or mature taro plants from infested sites to snail-free areas.

3. If you live in a snail-free lo'i or wetland district, monitor your area carefully and often. Do not allow huli from contaminated sites to be planted in your lo'i. If you see anyone dumping apple snails in an uninfested area report it immediately to the new statewide Pest Hotline (643-PEST) which is automatically routed to the appropriate agency on each

island and the Division of Aquatic Resources. Document the incident as much as you can (made much easier now that cell phones can take pictures).

4. If you are considering opening new lo'i, and any lo'i, 'auwai, or other water sources in the same system have snails present, it will contaminate the new patch. Using pipe instead of open 'auwai, or installing screens is not enough to prevent spread. Try to find an alternative, clean path for your water source that does not come from or travel through an infested stream, channel or patch. You may need to circumvent 'auwai with PVC pipe.

   If your stream is a source of snails, and there is no alternative source of clean water, consider copper screens at your intake as a repellent, accompanied by daily monitoring of the intake at the stream and the 'auwai. PVC pipe under 2-3 inches may not be appropriate in this case, as it can become jammed with snails.

<u>HDOA Quarantine Branch, DAR and ISCs</u>

1. Assist in distributing apple snail recognition and reporting information on each island.

2. Taro farmers report deliberate, malicious dumping of apple snails on several islands. Since 2003, state agencies have gained the knowledge and capability to respond to invasive species introductions much more effectively. Rapid response to reports of deliberate dumping in snail-free districts is critical to protecting this status. These agencies should collaborate with farmers in rapid containment and eradication for any new sitings within snail-free sites.

3. Assist taro farmers in development of a rapid response cleanup protocol with coordinated response on each island.

4. Implement a ban on the transport, distribution, raising or sale of apple snails within a 25 mile radius of snail-free districts on islands where the snail is present and a zero-tolerance ban on Moloka'i.

<u>Aquatic pet industry sector</u>

1. A few shops accept the return of pets that have become pests in Hawai'i (release prevention). Renewed publicity for an industry-wide “return program” encouraging customers who purchase tank-cleaning snails to return *any* snail species purchased to any aquatic pet shop when they no longer wish to keep them would help close the gap on this potential escape vector.

2. The aquatic pet industry in Hawai'i has voluntarily discontinued the sale of *Pomacea canaliculata*, however there are a few exceptions. An industry-wide agreement to no longer raise or sell *Pomacea canaliculata* within the state or for export; inclusive of internet sales, would remove the opportunity for future ‘accidents’ from customers.

<u>SEA GRANT</u>

1. When apple snails became a problem in taro patches across the state, SEA GRANT, in conjunction with HDOA, established a pilot project which attempted to turn the pest into

something economically beneficial, while reducing the population of snails in infested areas. Interviews with taro farmers have confirmed that a significant number of intentional introductions of apple snails to taro growing areas, wetlands, ponds, ditches and other fresh water sites that have occurred over the years were explicitly to establish populations to harvest as a marketable crop or as a food resource. Currently, several high-end restaurants, as well as open markets and grocery stores sell live and processed snails for consumption, including in Chinatown, O'ahu and Sack N Save in Wailuku, Maui. The income generated from these sales appears to be limited, however, it is impossible to estimate because much of apple snail consumption and sale is unrecorded. Where there is no market, there is less incentive to create new populations of the snails. It is recommended that SEA GRANT work with the food industry, particularly the chefs who participated in the pest-for-profit programs, and the general public, on a "disincentive program" to discourage consumer consumption and eliminate apple snails from restaurant menus, mainstream markets and "mom and pop" stores on all islands.

Moloka'i

Individual action – taro farmers:

1. Any taro farmer traveling to Moloka'i coming from an area where *Pomacea canaliculata* is present should clean all mud from and disinfect boots and shoes carefully. Tools should also be thoroughly cleaned and disinfected.

2. After hatching, apple snails are too small to be readily observed and may be transported on the huli (taro starts). Snails have the ability to seal their shells so tightly that the typical 5-10 percent bleach dipping solution used to limit the spread of disease may not affect or remove the snail. While it is a taro farming tradition to share huli between farmers, absolutely no huli should be taken from other islands to Moloka'i unless the farm of origin is guaranteed as snail-free.

'Onipa'a Nā Hui Kalo, farmers and agencies (public and/or private):

1. Only one Moloka'i-based source of traditional Hawaiian taro varieties currently exists. At least two dryland locations should be maintained on this island. The existing collection is in need of improved funding and staff support. This collection is key to the protection of taro varieties and should be expanded.

2. A huli bank of preferred varieties to assist new and existing Moloka'i farmers should be established in association with the traditional varieties collection to create a self-sufficient source of huli on Moloka'i.

B. Protecting and preserving traditional Hawaiian taro varieties, secure huli resources, cultural practice, and lifestyle choices

Existing traditional Hawaiian taro varieties collections are in poor condition. In recent years, many have been decimated by wild pigs. Some varieties have been damaged by disease. Almost all known collections, statewide, are incomplete. Both wet and dry sites are important to maintain because taro varieties may do better or exhibit differences in coloration and character in one condition or the other. Wetland collections are at great risk of loss due to apple snails.

Some limited distribution of traditional cultivars to taro farmers and gardens has occurred with marginal success. Multiple varieties are often planted in a single patch or field and their identities lost at harvest. Successive generations of huli have been limited from these attempts to share the burden of preserving and protecting this important gene bank and set of knowledge.

Individuals, agencies and organizations (public and/or private):

1. Apple snails pose a threat to maintaining the diversity of taro in Hawai'i. The loss of this genetic diversity would mean a loss of great magnitude to taro farming and the Hawaiian community. A minimum of three to four complete collections of traditional Hawaiian taro varieties need to be established or re-vitalized on each of the main islands; of which at least two are dryland collections.

   a. Dryland and wetland collections need to be protected from feral pigs and other animals. Hog-wire or electric fencing around established patches, especially at windward sites, will significantly reduce the chances of loss from these animals.[97]

   b. A long term goal of a complete collection in or near every taro-growing area in the state has been proposed.

3. Districts that remain snail-free, and dryland patches, should become the source for clean huli of key commercially and culturally preferred varieties for each island (huli bank).

4. Traditional Hawaiian varieties were often associated with specific districts. To increase protection and preservation of these unique cultivars, a program which supports taro varieties to return to the valleys and districts they were known to and encourages families from those areas to hānai (adopt) a variety and become the caretaker for its survival and expansion is recommended. Stewards would be responsible to propagate and multiply the variety, returning huli to collections and distributing to other taro farmers, to increase the chances of survival. In the same manner that an adoption process for a child is a serious commitment for the rest of the child's and the parent's life, so it is with a taro variety. A clear adoption protocol should be developed and families chosen through a rigorous interview process.

5. A dedicated coordinator's position should be funded to assist farmers who receive traditional taro varieties in tracking, maintaining, propagating, and distributing stock. Technicians are needed to assist current caretakers of existing collections in maintenance.

Botanical gardens

A number of established botanical gardens in the state had at one time, still maintain, or have recently established, partial collections of traditional taro varieties, including Waimea Arboretum and Lyon Arboretum (O'ahu), Limahuli Gardens (Kaua'i), Maui Nui Botanical

[97] Electric fencing can be run on solar power even in areas that receive high rainfall annually.

Garden and Keana'e Arboretum (Maui), and Amy Greenwell Botanical Garden (Hawai'i). These sites are important to protection and expansion efforts because of their ability to adhere to collection protocols and the presence of full time staff for monitoring.

1. It is critical prior to work on enhancing these collections that a Memorandum of Agreement support the establishment, care, documentation and distribution of traditional taro varieties back into the taro-farming community in collaboration with taro farmers and with full acknowledgement that these varieties are the legacy of Hawaiian cultivation without ownership or patenting rights to the gardens, researchers, or organizations involved in their protection.

2. Lyon Arboretum tissue culture lab has propagated traditional taro varieties in the past. Tissue culture could improve the rate at which traditional varieties could be restored to the field by making larger numbers of propagules available in shorter periods of time. Funding should be sought to allow this lab or another facility to recover this work as part of protection efforts.

<u>Hawaiian organizations</u>

1. As one of the primary agencies involved in supporting the perpetuation of Hawaiian culture in the state, Office of Hawaiian Affairs could play a key role in the long-term protection and preservation of taro farming and the 69 Hawaiian taro varieties that remain in the state. Several actions have been recommended including a assessment of the full spectrum of needs of the taro-farming community in order to better direct support from this resource. Several key elements that need attention include:
    a. The expansion and survival of traditional taro varieties.
    b. The development of knowledgeable growers - Master Taro Farmer trainings to increase the number of taro farmers able to identify, grow and protect this important resource and to design and implement integrated apple snail control efforts, resource materials to support these efforts.
    c. Farming family wellbeing and survival - supports such as health insurance, grants to support apple snail control efforts, low-interest loans for equipment, and community-based poi factories.
    d. Stengthening the understanding of the importance of taro among the general public (local and visitors), agencies, businesses and legislators – education campaigns and further assessment of the economic values of taro to other industries in the state.

2. Queen Lili'uokalani Children’s Center has played a steadfast role in bringing taro farmers together to help each other, shore up their knowledge and share their experiences with youth in QLCC programs and local communities. This important role should continue in order to build the next generation of stewards that will protect traditional taro varieties, grow kalo, and perpetuate the connection to Hāloa.

3. Alu Like, whose focus is Hawaiian health and welfare issues, has played a small role in apple snail control efforts in the past by providing summer interns for projects. The Plan recommends a renewal of this role through the establishment and funding of district level

apple snail 'swat teams' and a long-term apprentice program that would assist in maintaining traditional taro variety collections.

4. The Department of Hawaiian Homelands and Bishop Estate/Kamehameha Schools have access to land resources that would support the establishment of new collection sites for islands were existing gardens may not be available. In Waipi'o, Bishop Museum and Kamehameha Schools will be important partners in supporting these sites and in snail control efforts.

5. All of the above organizations, along with other Hawaiian health organizations and the Department of Heath need to assist in disseminating information on the environmental and health risks associated with the apple snail to kūpuna groups, families and communities, and in monitoring the health of taro farming communities.

<u>UH CTAHR</u>

1. Assist taro farmers in developing clean sources of preferred taro varieties to prevent transfer of contaminated huli from site to site. As with the botanical gardens, a clear MOA acknowledging that no ownership and patenting rights will accrue to the university or its researchers for traditional Hawaiian varieties of taro is needed prior to UH collaboration in this work, irregardless of where within the UH system the work is done.

2. Assist in the dissemination of accurate apple snail control information through the Agriculture Extension Service.

3. Work face-to-face specifically with the Filipino farming community to increase awareness of the risks and fines associated with the introduction of invasive species in Hawai'i (particularly into Hawaiian waters), about the negative impacts of apple snails in Hawai'i, and the disease risks involved in its raising and consumption. Clarify the difference between native apple snails in the Philippines and *Pomacea canaliculata*, and emphasize the damage this species has caused in their own homeland as well.

4. Direct the collective and individual resources and expertise of researchers within the UH system to pursue the research recommendations of this Plan as it relates to apple snail control and eradication efforts, in close coordination with taro farmers and 'Onipa'a Nā Hui Kalo.

7.2 On-farm best management practices

The following recommendations are made to promote improved whole-systems management and best management practices (BMPs) for in-field controls for lo'i kalo, including guidelines for huli and tool use, use of domestic ducks, maintaining farmer health, and other concerns.

A. WHERE ERADICATION HAS BEEN ACHIEVED

A rare few taro farmers have achieved complete eradication of apple snails from their lo'i. [98] **Eradication is possible** in small or isolated systems and districts where farmers communicate closely and slope and drainage prevents formation of standing water in lo'i for extended periods of time (greater than two weeks). This applies particularly to newly infested areas.

The following practices, in this order, make eradication possible:

1. Reduce snail population as much and as quickly as possible.
    a. Immediate and persistent removal of every visible snail at the first sign of infestation.
    b. Collection of snails during their most active periods, including at night.[99]
    c. Immediate removal of all egg clusters; pay attention to grassy areas along banks.
    d. Careful disposal of snails and eggs to ensure 100 percent mortality.

2. Remove opportunity for snails to deposit future generations.
    a. Remove huli to a safe site; create a dryland huli bank from which to restart taro patches after snails are gone.[100]
    b. Remove all other vegetation in lo'i to deprive snails of egg laying sites and food.

3. Further reduce remaining populations to minimize the number of snails that will end up in the mud at fallow.
    a. Create a shallow pond in a corner of each lo'i and bait to draw as many snails to the pool as possible.
    b. Remove and compost snails and eggs.

4. Long term fallow (1-3 years dependent on the geology, topography and climate of the area. See discussion Section 5.1).

    a. Keep fallow patches mowed or planted with a cover crop, or alternative crop such as 'uala, vegetables, dryland kalo, etc. if some short-term income is needed.

5. Reopen lo'i with care.
    a. Ensure a snail-free water source and 'auwai for re-opened patches to prevent reintroduction.
    b. Don't accept huli from infested areas.
    c. Implement a good stewardship protocol for workers and visitors to the newly opened lo'i, including clean boots and tools.

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[98] The Lind's of Kīpahulu, Maui were able to permanently eradicate snails in the adjacent district of Wailua and provided insight on the steps below.

[99] This works with a headlamp and bucket in the same way that people hunt for 'ōpae (freshwater shrimp).

[100] A dryland planting will eliminate the possibility that baby apple snails hidden in huli might survive to infest a new lo'i.

B. Coordinated set of individual practices for infested sites

Individual action - taro farmers

1. Clean tools and equipment after every use and between infested and non-infested fields.

2. Consider longer fallow periods (12-18 months) to starve snail populations in the soil (for areas that remain flooded year round, see 6.4 Perennial Wetlands, below).

3. Combine fallow with a cover crop with a tight root system that limits snail movement to the surface and that can be mowed and tilled in to improve soil nutrients prior to planting.

4. Tilling fallowed fields up to 3 times prior to planting is recommended by farmers with snail problems.

5. Water level management is an important part of snail control systems.

   A series of 3 dry-downs prior to planting will knock back apple snail populations to manageable level with proper attention to snail removal strategies.[101] Keep water levels shallow at each reflooding; use a bait to concentrate snails for hand picking or run ducks in the lo'i to clean snails out as they surface from the mud.

   Any number of natural bait materials work including rotten fruit (in Malaysia, jackfruit is used), chicken manure, or cut vegetation (some leafy material will attract snails faster than others, but apple snails will eat many plants).

   During dry-down periods, leave a trench along the inside of the patch, or an area where water can pond. Snails will congregate in these areas making it easier for removal and making it possible to scoop them out using a long-handled net to reduce back strain.

6. Egg cases are laid on plant stalks during the evening or right before dawn. Clean egg cases from plants at every chance to prevent snail hatches.[102] If eggs are dark pink, they have just been laid and the adult snail can be located down close to the base of the plant. If they are pale pink, they are close to hatching already.

7. Limiting disturbance in the taro patch has been part of traditional practice to prevent damage to taro roots. However, snails have made adherence to that practice difficult. The result has been increased disease in corms.

   Remove all weeds at a young stage, particularly kāmole (*Ludwigia octovalvis*), because eggs are harder to remove from them and farmers are less likely to clean weeds of eggs than from taro stems. Keep banks trimmed. If excess vegetation is not removed, pay extra attention to removing egg clusters from these plants.

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[101] Farmers use of dry-downs prior to planting varies greatly; however, three times seemed to be most effective. Managed dry-downs are also more cost effective than multiple deep tilling.

[102] The use of sticks as egg laying sites for snails has not proven to be effective when live plants are present.

8. Composting snails – mix with vegetative waste for faster breakdown and to reduce the smell of rotting snails. Applying lime may reduce insects attracted to the dead snails.

9. Maintain a mounded or dryland "huli bank" to reinvest in the lo'i in the event of heavy losses from snail predation. This will also reduce disease in huli.

10. A cover of azolla in a taro patch reduces water temperatures and provides a source of organic fertilizer to farmers. The plant is a free-floating fern that moves readily through pipes and 'auwai. Azolla becomes a part of apple snail dispersal pathways when lo'i are infested. Young snails hide in this material and can be transported readily. Don't move azolla from infested lo'i to other fields. To reduce infestation between fields, a boom in front of the exit pipe or puka wai (mākāhā) will help to hold back azolla in the patch but will not be 100 percent effective.[103]

12. Apple snails are known vectors for serious diseases; rat lungworm for which it is a carrier, and *leptospirosis* through cuts from snail shells that become an opening for infection. The tradition of bare feet in the taro patch is no longer safe in lo'i with apple snails (and Asiatic clams as well). Wear rubber boots or tabis to reduce the chance of cuts and infection. While gloves are also important in heavily infested areas, it is difficult to work efficiently and cuts to the hands are frequent. Cuts should be treated immediately. At the onset of flu-like symptoms farmers should be tested for *leptospirosis* at a health facility to reduce delays in delivery of medication should tests prove positive.

C. Domestic ducks as part of comprehensive, strategic controls

The use of domestic ducks has been key to knocking back snail populations to manageable levels. Where multiple strategy control systems are in place, the addition of domestic ducks significantly reduces the time and labor spent in hand removal of snails and reduces crop loss and damage to less than ten percent.

1. A guideline for use of domestic ducks as apple snail control has been developed through a collaborative effort between taro farmers, wildlife and invasive species experts from the Hawai'i Department of Agriculture Plant Quarantine Branch, DLNR-Division of Forestry and Wildlife and the U.S. Fish and Wildlife Service. The guideline is voluntary. It provides recommendations for the most efficient use of domestic ducks in a manner that prevents interaction with native koloa to the highest degree possible and is attentive to the threat of disease outbreaks such as West Nile, avian malaria, avian flu and botulism (See the appendix for the full protocol). The guideline recognizes the existing limitations currently faced by farmers (economic, labor, time etc) and the concerns for preserving the genetic integrity of the native koloa. DOFAW and USFWS wildlife specialists have expressed willingness, given an acceptable protocol for domestic ducks in taro patches, to support this snail control measure in areas where wetlands and lo'i kalo co-exist (duck roundtable Jan 2005).

[103] A screen to catch azolla will rapidly become clogged. Where snail populations are high, azolla is usually not found, as it is rapidly consumed.

2. Development of a controlled domestic Pekin duck breeding program on each island specifically to help taro farmers maintain their flocks for apple snail control is urgently needed with the assistance of HDOA and USDA.

3. Development of a source of mullards (sterile ducks) for use in protected wetlands where koloa populations may necessitate additional assurances is an alternative to the use of Pekin. This would guarantee that no fertile eggs would be produced even if the unlikely event of pair-bonding were to occur. However, mullards should be considered only as an alternative to Pekin because of the difficulty of producing these ducks. They are also untested for their use in taro patches and in apple snail consumption. Farmers have concerns regarding whether they may be too destructive of lo'i banks, as they are derived from a Pekin-Muscovy cross. Muscovies are notorious for their ability to tear up dirt embankments.

<u>Individual action - taro farmers</u>

1. Use ducks wisely in controlling apple snails. Implement the domestic duck guidelines to the highest degree possible.

2. Educate other farmers about the use of domestic ducks for apple snail control and best practices for on-farm ducks.

3. Be aware of the various avian diseases that may affect your ducks and contact the appropriate agencies in the case of sickness in any of your flock. Consider partnering with USFWS to pro-actively monitor for potential disease outbreaks.

4. Farmers may need to use hog-wire fencing around patches where duck controls are implemented to protect them from free-roaming dogs.

<u>Agency action</u>

State and federal collaboration to develop a controlled domestic duck supply for taro farmers on each island is requested.

1. Pekin ducks are more scarce in the islands than other breeds but are considered most appropriate for lo'i near protected wetlands because of their size and visibility. Funding to develop a pool of these ducks specifically and only for apple snail control is needed. Kanu o ka 'Āina Charter School or the agricultural program at Honoka'a High School (Hawai'i), Waipā Foundation (Kaua'i), and Paulo Fujishiro (Maui) have volunteered to collaborate in this effort. Organizations or individuals on O'ahu have not yet been identified, however at least two locations are needed (Waialua and Windward)

2. Mullards are not available in Hawai'i. No ducks are permitted for import due to risks of avian flu and West Nile Virus. HDOA is encouraged to assist in testing these ducks in taro patches under a research permit to determine their viability. Metzer Farms of California is familiar with the issues facing taro farmers and may be available to help train taro farmers and agriculture extension personnel in the production of mullards and

Pekin in Hawai'i and to help establish a viable mullard project specifically for Kaua'i and the Hanalei Refuge. A research permit for egg importation may need to be considered.

3. In order to ensure the highest degree of protection in regards to disease, it is recommended that DOFAW test captive-reared domestic ducks for malaria prior to distribution to farmers, if they travel between islands. This scenario is only likely until a consistent source of apple-snail control ducks is available on each island.

4. In conjunction with the state's avian flu monitoring plan, USFWS Pacific Islands Office Invasive Species Division has an interest in testing domestic and feral duck populations for disease occurrence in a regular monitoring program. Testing of feral duck populations will also include removing them from the wild upon capture (J. Burgett, pers. com 2006). It is recommended that these ducks be pinioned, banded and provided to taro farmers as a backup source of ducks for snail control efforts, a winning situation for both groups.

5. Removal of domestic ducks from farms by state or federal agencies as part of disease control measures will need to ensure replacement of any birds with the appropriate breeds to support continued apple snail control efforts to prevent hardship for farmers and rebounds in snail populations.

5. The USDA NRCS has a new cost-share practice that provides for the installation of hog-wire fencing and covered pens to protect ducks used in alien species control in taro lands. In addition, this practice requires the use of only Pekin ducks, which are a scarce commodity. It is recommended that until the steady availability of Pekin ducks can be assured that existing domestic breeds be allowed for use under this practice.

6. Not all farmers lands meet the criteria for USDA cost-share programs. Some cannot afford to enter into cost-share agreements. The US Farm Bureau, HDOA, the state's Small Business Innovations Program, the Counties, OHA and other partners are encouraged to make available small grants to farmers for the purpose of installing protective fencing and pens for these ducks.

7. The extreme situation in Hanalei, Kaua'i has placed taro farmers and the industry, and wetland managers in a difficult position. It is recommended that the USFWS Wildlife Refuge staff work closely with taro farmers to improve this situation. Realistically, apple snail populations are so high within the Refuge that domestic ducks may be the only measure available at this time with the capability to reduce snail populations to manageable levels in the short term. A carefully monitored, temporary domestic duck use program should be strongly considered. Consider a domestic flock that is raised and housed outside the Refuge and brought in and out daily for control efforts.

8. It is recommended that interested taro farmers receive training in the identification of koloa, koloa hybrids and mallards to increase knowledge towards feral duck population control efforts.

9. Currently there is limited overlap between feral duck population locations and the small number of sites where farmers are currently using domestic ducks for apple snail control.[104] Feral duck populations should be removed from all taro-growing areas. This will provide federal and state agencies with clear discernment regarding any potential interactions between domestic ducks used by taro farmers and koloa, as well as improve koloa habitat. The possibility of migrant mallards and other duck breeds establishing populations in taro-growing areas is real. Migratory birds are protected by law. Agencies will need to consider alternative means of dealing with these birds which mingle with koloa populations.

D. Natural cycle based strategies

Individual action – taro farmers

1. Attack all parts of the snail cycle; hand-picking large adults, allowing ducks to feed on small and medium sized snails, and removing eggs to prevent new introductions to the populations.

2. Pay close attention to seasonal changes in snail behavior. Snail populations spend more time in the mud during winter months and boom in warmer weather. At the transition zone (usually March) when snails become more active, hit them hard as they come out of the mud with a variety of control measures with the goal of significantly reducing the number of snails that reach maturity during summer months.

3. Monitor 'auwai and intakes and remove snails that occur in these areas wherever possible to eliminate reintroduction sources within your control.

4. Stretch fallow periods to kill off smaller snails under the mud. When fields are re-flooded, this leaves only larger adults that are easier to see and remove. A minimum of 6 months is recommended; a year is better, and has the added benefit of improving overall soil health. This will mean redesigning planting and production cycles on-farm in a way that will allow you to meet production orders. This measure requires enough available lo'i and fallow lands to increase fallow periods in currently cultivated patches.

E. Landscape and ecosystem level strategies

Community action

1. Isolate infested 'auwai and lo'i systems wherever possible to prevent further contamination of larger areas. Consider circumnavigating the traditional 'auwai system with PVC pipe so that water from an infested set of lo'i by-passes clean lo'i to reduce farm-to-farm and patch-to-patch spread.

2. Clean and control districts from mauka to makai (or from uppermost lo'i to those in the bottom reaches). If farms most mauka in the system remain infested, every farm,

[104] Feral duck population maps. USFWS 2005.

waterway and wetland below is still vulnerable to infestation from the uppermost patches. The same is true of fallow patches and wetlands that are part of the system.

This may be one of the most difficult and uncomfortable strategies to work out. However, it unlikely that large taro growing areas will be able to reduce or eliminate apple snail populations without some basic levels of coordination for control efforts. Even where actions occur on individual farms, coordinating the timing of those actions between farms can contribute significantly to reducing overall snail populations in the system. The same applies to fallowed parcels and wetlands within taro growing areas. Without coordinated participation by other land managers/owners, including state and federal agencies, flooding events will continue to redeposit snails back into farms.

3. Coordinate timing of control measures across farms in connected systems in conjunction with the seasonal cycles of the snail to further increase effectiveness.

4. Coordinate long term fallows within the whole system in a strategic manner so that upper field snail populations are reduced or eradicated first and the number of snails moving into lower fields are ultimately reduced.

<u>Agency action</u>

1. The Department of Aquatic Resources conducts occasional alien species control efforts in streams around the state. The methods used may be useful to taro farmers. Coordination and training between taro farmers and local DAR offices during these events should be considered so that whole valley systems might be addressed systematically rather than in isolated sections. Training taro farmers in the methods, equipment and materials required to conduct such work would expand existing DAR staff capabilities and provide communities with a landscape level tool to approach snail control.

2. Invasive Species Committee and DAR staff on each island may be able to assist in community level coordination of apple snail efforts as described above.

7.3 Other farm strategies

<u>Agency action</u>

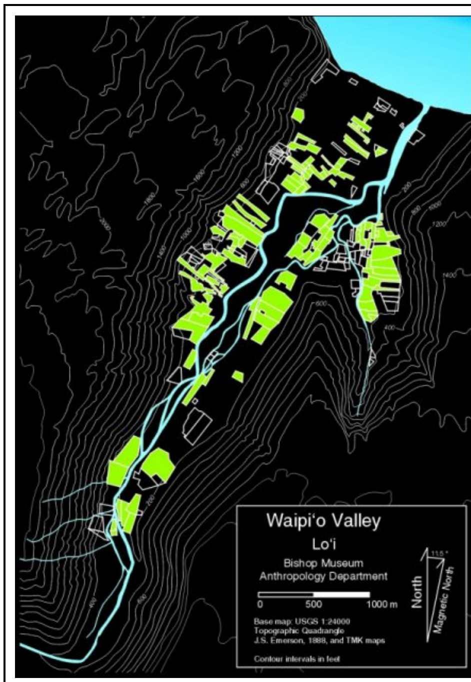
1. HDOA assistance is requested to bring federal "crop disaster funding" to the state specifically to help farmers combat apple snails. Initial suggestions considered the possibility of compensation for fallow (crop loss), however, farmers were more in favor of supports for active fallow measures such as cover cropping and fallow maintenance (ie. mowing and tilling); field preparation costs after fallow had ended; protective fencing, pen costs and feed for ducks; and PVC pipes to circumvent infested 'auwai. Alternatively, access to snail-free lands to farm were also proposed (ie. through lease supports or an MOA with DLNR or USFWS).

2. Current conditions set for agricultural tax breaks and USDA Farm Bureau loans may need to be re-assessed to support long-term fallow. Under current conditions which determine the number of years a farmer must be actively cultivating in order to receive such benefits, taro farmers who need to use long-term fallow for apple snail control may not qualify. A Conservation Plan with local Soil and Water Conservation Districts (NRCS) may count as a third-party verification to such agencies, however, this may not be practical for taro farmers.

3. Improved disease and rat monitoring, and vector control in taro growing areas by the Department of Health is recommended to prevent disease "hot spots" from occurring.

7.4 Perennial wetlands

The history of perennial wetlands in Hawai'i are unique in the United States. Oral history and archaeological evidence indicates that Hawaiians utilized river flats, perennial wetlands and estuaries, particularly for lo'i kalo and loko i'a (internal fishponds), throughout the islands from the time of earliest arrival; at least 800AD (Athens 1997) and by some estimates as early as 300AD (Kirch 1985). These ancient lo'i and loko i'a are still visible at many sites. For centuries this use kept perennial wetlands open and relatively free of invasive species, as well as provided extensive wetland waterbird habitat (Greer 2005). Many lo'i kalo in perennial wetlands were only abandoned in the 1950s, while others, such as Halawa, Hanalei, Ke'anae, and Waipi'o were never completely abandoned. What are considered to be "wild" lands by some, are in reality, abandoned agricultural lands that have been in use for more than 1,200 years and have only recently been recolonized by invasive vegetation.



Waipio Valley lo'i kalo map circa 1888. (Bishop Museum)

Waipio Valley 2004 (Bishop Museum). Note the ironwoods, hau and other vegetation that have established behind the beach. In this year, the first set of lo'i still in operation are much further back from the mouth of the valley (red arrow) than even the 1940s. The wetlands at the front of the valley are unmanaged and densely vegetated. They harbor apple snails, as do abandoned lo'i.

It has become increasingly important to protect our rapidly dimishing wetlands in the state. However, prevailing wetland and wetland wildlife management models in Hawai'i have been shaped primarily by the national experience which stem from a “wilderness” perspective rather than the historical evidence of these islands. This management perspective has contributed to rapidly increasing apple snail populations in those valleys with protected wetlands.

A. Lo'i kalo

In the Hawai'i context, lo'i kalo are clearly part of perennial wetlands. Where lo'i are located within or on the boundaries of perennial wetlands, they are typically low-lying bottom lands characterized by high water tables and saturated soils. Lands closest to the ocean are least likely to be able to dry out completely. They flood quickly in heavy or persistent rains and retain standing water for several days. Waipi'o, Hawai'i; Ke'anae, Maui; Kawainui Marsh, O'ahu and Hanalei, Kaua'i are an examples of this type of site.

Individual lo'i

Individual action – taro farmers

Many of the practices described above will apply even to low bottom land lo'i. One practice stands out as infrequently used but still valuable.

1. Long-term fallow with cover or alternative crop appears to be effective even in the most frequently flooded zones. For a dramatic reduction in apple snail populations (or eradication), a fallow of two to three years is recommended. For this to be economically feasible for farmers, additional lands may be required to allow for fallow while still meeting production demands. Maintaining a managed fallow is critical for these fields as weed-filled fallows, which may have standing water at times, will continue to provide habitat for the snails.

   A densely-rooted cover crop with a mow and till program or even just a regularly mowed field will interrupt snail breeding and laying cycles. The goal is to hinder the movement of snail upward from the mud to the surface where they can begin to forage and lay eggs again. Keeping plant stems low to the ground will remove egg-laying sites most of the year and submerge egg clusters, if they show up, when the field ponds.

2. Monitor fallowed fields regularly for the appearance of snails and eggs and remove them if they appear.

3. Keeping lo'i weed-free is important to reducing egg-laying sites for apple snails. Trenching and baiting can be applied to attract and reduce snail populations.

4. The ISSG recommends removal of all vegetation and obstacles immediately around fields to the extent possible to remove egg deposit sites. Keep banks trimmed consistently.

5. The colder the water, the slower the growth and maturity of the snails and the fewer egg clusters will be laid.

Federal and state agency action
In protected wetlands where lo'i kalo and extremely high apple snail populations exist; farmers are ham-strung in their ability to fight apple snails on almost every front because of the restrictions often related to these properties (ie. federal and state protected wetlands and refuges). The two best tools for apple snail control (the ability to fallow long-term and ducks) have not been accessible to taro farmers in protected wetlands. In Hanalei, fields must be held open with standing water for a length of time after harvest providing prime conditions for rapid growth of apple snail populations. Managing solely for wildlife has resulted in tens of thousands of dollars worth of loss per year to farmers due to snails (along with the other impacts discussed in Section 6).

1. Coming to terms with the relationship of lo'i kalo to wetlands and waterbirds in the Hawai'i context will open the door to a large number of productive partnerships between agencies and the local community. Agreements are needed that can support long-term fallow and alternate lands that might be opened for lo'i kalo so that farmers have the ability to rest infested fields for the needed amount of time and still meet production. This means access to lands in a timely manner and for long enough so that as acreage goes out of production in one place it is coming into production in another and so that lands can lie fallow long enough to have an impact on snail populations. It also means working with farmers to determine what the right lo'i lands are, together. The requirement to leave open standing water in lo'i after harvest should be revisited and redesigned based on on-farm control recommendations. The reduction in snail populations is a win for both wetland managers and taro farmers.

2. A temporary exemption on the use of domestic ducks in protected wetlands where lo'i kalo are actively farmed to drop apple snail populations in the taro patches is compelling. The use of brightly banded, highly visible Pekin ducks, adherence to the guidelines in the appendix of this Plan, and the inclusion of fencing to protect ducks from dogs will help to keep such an effort carefully controlled. Appropriate permits and shipment of ducks between islands may be needed until such time as a controlled, sustainable pool of Pekin ducks can be developed on each island.[105] Testing for avian malaria, bird flu and West Nile virus should be administered regularly by USFWS and DOFAW personnel. Raising and housing these domestic ducks off-site and bringing them in to forage for snails during the day may be an appropriate alternative to individual farmers with individual flocks. To work, such a program would require careful coordination with farmers and in a landscape level strategic application so that multiple farms are treated simultaneously.

Landscape and ecosystem level strategies – lo'i systems

The taro growing areas of Waipi'o (Hawai'i), Hālawa (Moloka'i), Kīpahulu and parts of Ke'anae (Maui), and upper Waiāhole and Kahana (O'ahu) share in common cooler water temperatures than are accessible to many taro lands due to higher volumes of water in the streams that feed these systems. The benefits of this faster, colder, and often deeper water

[105] Sustainable means there are enough ducks in the pool to replace ducks that may be killed by dogs, stolen, or reach an age where they are no longer productive.

are three-fold; a healthier native stream biota, reduced alien aquatic species populations instream, and reduced disease rates in lo'i kalo. Of this group of sites, only two have apple snails (Ke'anae and Waipi'o); concentrations are found where waters are slower.

In a study from Japan, researchers found that where water velocity was greater than 50cm (2.6 feet) per second, *Pomacea canaliculata* was almost completely absent (Kenji 2004). Cooler water temperatures slow snail maturation and egg production rates (Cowie 2002; Kenji 2004). This is verified by farmer observation on all islands even in heavily infested locations such as Hanalei (Kaua'i).

The second factor in reduced apple snail densities in lo'i kalo is the well-managed use of domestic ducks to control snail populations within individual lo'i in various parts of the system. Their strategic application to lo'i in perennial wetlands is an important stewardship tool. For heavily vegetated, difficult to manage sites, the organic compound from Maui (discussed briefly in the control methods section) may provide the strongest hope for real landscape level control, although availability may be several years away dependent on laboratory trials to determine efficacy and impacts to native biota.

<u>Agency action – state and federal</u>

1. Evidence suggests increased water source flows (lower water temperatures) should be an important system level component in slowing the exponential growth rates currently seen in apple snail populations. This requires a stronger commitment from the state to restore water to the streams that support these important wetland systems throughout the islands.

2. See the above comments on long-term fallow and alternate acreage for kalo production to reduce apple snail populations to manageable levels. State and federal landowners are important partners in realizing this option. Careful layout of new fields that follow snail-free hydrological flows will improve the application of fallow. Without this shift, such massive infestations as those found in Hanalei will eventually cost the entire wetlands their structural and functional diversity.

3. Reduction of invasive vegetation in fallow fields and surrounding landscapes is important for shrinking available snail egg laying habitat. Species such as California grass, rice grass, kamole and hau bush should be high on the list of targets for removal. Time vegetation removal to seasonal cycles (before egg laying ramps up in March) and design removal schedules to work from the top of the system towards the bottom.

4. Non-participating landowners within a system will reduce the efforts of farmers to the equivalent of tredding water. If there is to be forward movement in the control of this invasive species, it is critical that all those who have control over decision-making and active management for these sites become part of the solution. Where farmers may be overwhelmed by work, assistance to help reduce snail populations may be needed. Altering the course of water to avoid passing through heavily infested parcels may need to be considered to support farmers downstream until uphill infestations are reduced or eradicated

4. There is an urgent need to develop organic compounds that kill apple snails but do not harm native aquatic biota to control the snail in landscape level infested water systems.

B. Natural wetlands

Natural wetlands are one of the major unaddressed points in the "system" of apple snail habitat. Core and Secondary wetlands listed in the waterbird recovery plan for Hawai'i (USFWS 2005) are infested. There are a number of unknowns regarding the level of infestations at these sites. Several factors have influenced this, including that the apple snail has not been a high priority for wetland managers, a lack of knowledge regarding the degree of damage to natural wetlands the snail is capable of, and, in densely vegetated sites, the potential that the snail population may be hidden below vegetation mats that mask population density. This has resulted in the position that the situation "is not that bad" in protected wetlands. Based on existing research and available information, it is clear that left unchecked, things will get "that bad." As this report evolved, the observations of long time residents in taro growing valleys has helped to pull together a picture of how at least some level of control over apple snails might happen in natural wetlands around the state.

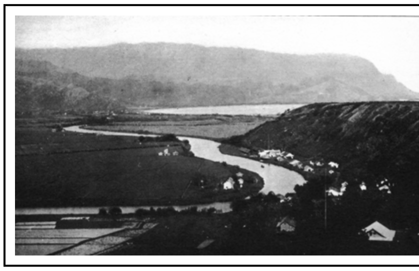
Landscape and ecosystem level strategies

The example of Waipi'o Valley provides some insights. Farmers record that heavy flood waters (equivalent to a 10 to 25 year event) have "cleaned out the system" and brought snail populations close to zero at least once.[106] This flushing action is supported by a return of water to Hi'ilawe Falls and by high rain events. The power of additional water in the system has reduced water temperatures and increased native biota. It has also increased the ability of the water to break through soil deposits at the mouth of the valley and reconnect to the ocean, despite uncontrolled alien vegetation growth in the wetlands and along the hardened beach zone. Excessive non-native vegetation in the wetlands at the front of the valley remains a hindrance to restoring these natural patterns.

Silt trapped by excessive alien vegetation at the mouth of the Waipi'o Valley causes water to back up into farms at the most makai end of the system. The river breaks through the beach during heavy rains.

[106] Reinfestation was human-related.

Along with diminished stream flows, the Hanalei river system is influenced by the tides. If the tide is high, water coming down from the river is pushed back toward the estuary; however, even this river had a much cleaner exit historically than is present today, as illustrated by this picture of the mouth of the river, circa 1898.



Hanalei Valley at river mouth at the time of Queen Lili'uokalani (Lili'uokalani 1898, pg222 from the web).

Heavy vegetation in both the 'auwai and the river itself need attention to improve these flows. Damage to the intake system which feeds taro patches throughout Hanalei has also contributed to reduced water availability. A temporary repair of the intake in 1995 is now a breach of more than 30 feet which requires constant monitoring. After a flood, the entire valley goes without water.

By recognizing the traditional ahupua'a cycles within an place rather than the distinct boundaries of property owners, it is easy to see the area as an interdependent system. Following natural flows in a mauka to makai direction provides insight into key nodes in the ecosystem that are in need of attention. The USFWS Hanalei Refuge ponds, which are heavily infested by apple snails, are located above existing taro fields. Each time heavy flooding occurs, snails from these ponds are flushed into downstream patches and into the Hanalei River, where the action of the tides prevents their removal.

Kawainui Marsh lacks the strength of water coming into the system and a network of outlets for flood waters that would facilitate flushing of apple snails from the larger landscape although significant headway is being made along the channel at the bottom of the marsh through a collaboration between DOFAW and the local community. A few open ponds and a main channel through the center of the wetland remain open year round. Siltation, vegetation and microtopography within the marsh itself provide ideal habitat for the snail. The difficulty in assessing the degree of snail infestation in this marsh is related to a vegetation mat so dense that the water persists below the surface of the root mat in most places except during heavy rains when water depths can reach at least three feet. Non-native California grass (*Brachiaria mutica*) and cattail (*Typha latifolia*) dominate much of the marsh's expanse.

Kawainui Marsh 2003. (PonoPacific)

All three of these wetlands have areas of deeper, open water and large sections of dense alien vegetation. Snails appear to prefer shallower waters in Hawai'i. Where water depths reached three feet or more in marshy areas with no vegetation, relatively few snails are observed.[107] Edge areas, slow water, or areas were snails can float to and live on vegetation mats growing in deeper water support both snails and egg-laying in these wetlands. In two areas of Maui, the low-lying branches of hau bush growing in water were a host site for egg clusters (Levin, field notes 2004). This is also true in Hanalei, where apple snails and eggs are abundant in

[107] In their native Brazil, they appear to inhabit deeper waters from 1 to 5.6 feet deep.

the hau bush that encroaches into the river and slows water to almost a standstill in some areas.

Each valley has its own characteristics and behaviors. What works for one, may not for another. The cases point to critical nodes in ecosystem energy flows that if managed, may help to reduce apple snail populations and improve overall wetland health. Key recommendations can be made for all wetlands related to water flows. Site specific recommendations are also made.

<u>Agency/taro farmer action</u>

1. A collaborative study of historic patterns of water circulation including those places where water used to flow directly out, or "break through" to the ocean in the largest wetlands in the state is merited. Information may already exist for some sites. Assess the pattern of currents at the mouth of these wetlands (including seasonal changes) to determine the likelihood of snails flushed to the ocean reaching other freshwater sites along adjacent shorelines.

2. Incorporation of this information into new or existing flood control and open shallow water management plans that focus on re-storing these systems to the ocean, as they once flowed. This may not possible for all sites; however, even Kawainui Marsh with its man-made berm and homes on the makai side of the berm, can potentially improve existing conditons.

<u>DLNR/Office of Planning</u>

1. Traditional lo'i systems are being disrupted more and more frequently by permits that allow homes to be built on top of old lo'i fields, even within sites that are still farmed. The result is a breakup of natural flooding and water flows and the systems that were carefully designed to handle them. Such lands often fall within State and County SMA (Special Management Area) zones. Existing state rules for these areas need to be strengthened to protect and prevent disturbance of whole lo'i kalo systems, better preserve the natural freshwater flows into and out of wetland and riparian ecosystems, and allow for restoration and maintenance; a key step in reducing alien pest species populations in existing wetlands. This will also help to reduce future liability to the state and its counties by removing the chance of development, particularly along makai boundaries of such sites.[108]

<u>Agency/Private landowner action</u>

1. Implement and support the reduction of alien vegetation along river corridors, 'auwai, internally within wetlands, and between wetlands and beaches to improve natural water

[108] Hawaiians built lo'i kalo and fishponds in a manner which did not hinder the natural flows of the system. Past flood events at Kawainui Marsh, and the subsequent berming of the wetland; building permits for homes built in lo'i and fishponds that flood annually and in gulches and flood plains that fly in the face of common ecological sense, are prime examples of the danger of overriding this knowledge on islands where water drops steeply and moves rapidly over short distances and where wetland soils are present.

cycling for mauka to makai systems. Benefits to nearshore reefs and fisheries will accrue accordingly. Encourage and support managed fallow on leased lands.

2. Snail populations within state and federal wetlands need to be reduced or eliminated; however, at this time the only option available to such sites may be hand-picking. It is long past time that public wetland managers and private landowners understand the impossibility of hand-picking snails and the back-breaking work that farmers have done for the last two decades in order to deal with this pest. Failure to participate in solutions to this problem in the past, or to continue to do so, make the best efforts of taro farmers moot. It can not be emphasized enough, that other options, as described in this Plan, are required. The added risk of potentially expanded botulism vectors should increase the urgency of control efforts by wetland managers.

   Waipi'o Valley
   This land is owned by the Bishop Museum. A private/public agency collaboration is recommended to remove the ironwoods on the beach where the river usually breaks through[109] and reduce alien vegetation in the wetlands, with a priority on tree species and dense shrubs immediately mauka of the ironwoods. Hau bush and other trees that cause narrowing of the river channel throughout the valley should be addressed.

   Systematic removal of alien vegetation in the body of the wetlands will provide the best opportunity to reduce apple snail habitat. Strategic replacement with natives such as kaluha and makaloa will present less likely egg laying sites.[110]

   A small upstream taro area deeper in the valley has recently been re-infested with snails (2005). The application of practices outlined in this Plan, including integrating domestic ducks may significantly reduce, and could even eliminate this population. Special attention should be paid to protecting lo'i kalo, 'auwai and the stream makai of this site from apple snail invasion. Fallow lo'i between this area and downstream lo'i should be carefully cleared and controlled for infestations and monitored on a regular basis.

   Paukūkalo springs, Wailuku, Maui
   This 60 plus acre site has both natural springs and a wetland almost completely covered in hau bush. Snails are found in all of the springs within accessible parts of the property; no assessment of the hau bush area has been made. Ponding occurs under the expanse of hau which covers much of the parcel and is likely to harbor additional snail populations. Collaboration with the NRCS Wetland Reserves Program would be appropriate here to assist the landowner in reduction of the hau overstory, invasive species control, as well as overall wetland habitat improvement. The property would be a valuable contribution to coastal wetland resources on Maui, potentially doubling the length of the protected

[109] Campers and surfers now use the ironwoods, however reducing their presence in the area of the river mouth is critical to improving natural water cycles. This invasive tree could eventually be replaced with milo and kamani if a portion of tree break is still desired for further down the beach.

[110] Soft-stemmed plants that cannot support the weight of the snail or its egg clusters are avoided by mature snails.

wetlands along West Maui. This site could also yield information on whether subterranean snail movement can occur between ponds both on and off site.

Hanalei Valley and the Hanalei Refuge
Hau bush that narrows the river channel and slows or traps water should be a high priority for reducing apple snail habitat in the valley. USFWS Hanalei Wildlife Refuge ponds above taro lo'i are heavily infested with apple snails and are the source of continual reinfestations to taro farms and the larger wetland. This clearly needs immediate attention, in a manner that also causes no damage to taro crops below the ponds or to native birds. Attention to snails in the upper ponds will yield results within the lower reaches of the system. At the same time, areas where snails are deposited at the mouth of the river should also be addressed to prevent tidal redeposition of snails across lo'i. Assessment of back-flooding patterns in the lowest reaches of the river may provide insight for how to prevent reflooding into these areas. Care should be taken to also understand the importance of these backflows in the bay to local fisheries prior to any action. The water intake that feeds lo'i kalo in the valley is under the jurisdiction of both the state and federal government. Taro farmers, along with USFWS Refuge staff have invested considerable time and money in remedial repair efforts. A legislative provision or allocation from the current flood disaster funds may be necessary to permanently repair the intake and keep waters flowing into the valley.[111]

Kawainui Marsh
The multi-million dollar mitigation plan for this marsh does not contain any action for apple snail control. A thorough assessment of the marsh to map key snail populations (evidenced by the presence of egg clusters) within its boundaries and leading into or out of the marsh where apple snail populations congregate is needed, including the adjoining channels and Ka'elepulu pond at Enchanted Lakes. This should be done during the summer season when snails and eggs are most visible. First stage efforts should concentrate on reducing or eliminating sources coming into the marsh. Reduction of alien vegetation that inhibits waterflows in and out of the marsh is a daunting task but must be addressed if a reduction in apple snail populations is to be realized. A broader network of open water throughout the wetland would improve the flushing capacity of the marsh.

Campbell National Wildlife Refuge
Managers at this wetland have been addressing apple snail populations through salt water intrusion. Documentation of the techniques and effectiveness of this method for brackish areas is recommended so that others may benefit from what is learned here. All ditches and drainages into and out of the Refuge should be cleaned of vegetation, banks kept well trimmed and snails treated at the source. As with other sites, consistent attention to egg cluster removal is important to slow population growth. Collaboration with mauka landowners is recommended to reduce those snail sources entering into the refuge.

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[111] Since 1995, taro farmers have rented an excavator as the cost of $2,000 per week plus insurance and the USFWS Refuge has used it equipment to make repairs on the intake (R. Hariguchi, pers. com. 2006). Immediate action will be necessary to take advantage of any opportunity that might be available through current flood disaster funding.

CGAPS partners action

1. Without reduction or eradication of apple snails in key wetlands, endangered waterbirds will continue to remain at risk, even with increased numbers, due to impoverished food resources, increased rat and mongoose presence and potential disease vectors. The addition of apple snail control measures as part of actions for delisting endangered waterbirds in the *Draft Revised Recovery Plan for Hawaiian Waterbirds* would better protect the birds future. Under Recovery Action 1: Protect and manage all Core and Supporting wetlands:

   Recommended addition: "*1.3.8 Eliminate or reduce and monitor alien mollusk populations that threaten to impoverish wetland habitats and/or negatively impact adjacent lands where birds may forage or nest, particularly taro farms and fallow taro-growing lands.*"

   This language would also allow waterbird managers to address the incursion of Asiatic clams into these same areas.

7.5 Education outreach

One of the biggest failures of pest management in Hawai'i in relation to the apple snail occurred at the point of introduction of this species into taro farms as an economic enterprise. It has been said that taro farmers failed to understand the rapid growth and damage the snail would cause (Tamaru, Ako, and Tamaru, 2004). In truth, farmers did not have access to that information until they had observed the snail for some time. By then, the damage had been done. The information was, however, available from Asia and Southeast Asia by 1981 and accessible to state agencies and researchers. Had the Maui Economic Opportunities program, which was part of some of the initial start-up backyard projects, chosen to investigate the proposed "opportunity" more closely, it may have been able to determined that the risks were too high. It is hoped that at a very basic level, this Plan will educate a broad spectrum of people and agencies in the state about the cost of ignoring the warning signs for such species and motivate a larger sector of the community towards preventative action against the next aquatic invasive.

Public education goals outlined in the state *Aquatic Invasive Species Plan* clearly apply to outreach education goals necessary to improve participation in apple snail control efforts.

In order to increase the number of people knowledgeable about apple snails it is important to raise public awareness about the pest. However, the challenge of effective invasive species education is not just how many people are reached but whether or not individual habits, attitudes and beliefs actually change (buy-in).

'Onipa'a Nā Hui Kalo and other taro organizations

The permitting of apple snail enterprise development was a direct result of incomplete knowledge in the case of state and county agencies and community groups.

1. Develop a series of materials and network of speakers available to do presentations at a wide variety of public forums. Agencies, legislators, UH researchers, businesses, neighborhood boards, school PTAs, public and private housing tenant associations, cultural organizations (multiple languages) and other organizations such as Kiwanis and Lion's clubs present important opportunities to educate and spread the information further.

2. Increase the number of knowledgeable people able to conduct detection and monitoring.

3. The likelihood that initial introductions of *Pomacea canaliculata* to Hawai'i came through undetected importation directly to taro growing areas and through inadvertent introduction by mistaken identity with similar edible snails, such as bisocol suggests two important points of outreach education on the proper identification of this snail:

   - Port of entry identification
   - Port of exit from countries of origin (stop them before they enter shipments to Hawai'i)

   In addition, the aquatic pet industry has indicated difficulty in distinguishing between the many varieties of apple snails that they receive for sail in pet shops and online. This group should be included in identification training as well.

4. Current perceptions that taro is a minor crop and that apple snails only impact kalo are widely inaccurate. Educating state and federal agencies, including the Hawai'i Invasive Species Council (HISC) and its subgroups on:

   - the significance of taro culture to Hawai'i,
   - its role in wetland ecosystem health, and
   - the predominance of non-lo'i lands (95%) that are at risk from invasion by apple snails,

   is a key step towards allocating resources to recommended actions.

5. Issue an immediate Invasive Species Alert to all taro farmers in the state.

6. Provide an annual reward for the most effective on-farm apple snail control systems. Document and feature these farms and their suite of methods at a variety of forums such as taro festivals, taro farmer meetings and the CGAPS apple snail web page.

7. Educate the general public about the cause of poi and taro shortages and the impact apple snails have to crop yields.

8. Educate consumers about the negative impacts of the snail and encourage consumers to refuse to purchase or eat "Hawaiian escargot" in local restaurants and markets.

9. Educate chefs about the dilemmas of encouraging the consumption of local apple snails.

10. Use the opportunity of annual taro festivals and community celebrations on each island to continue education outreach about apple snails to the general public and local businesses to the highest extent possible.

11. Develop an apple snail exhibit that can be lent to public libraries and displayed at taro festivals.

12. Share educational materials across organizations and with agencies to increase dissemination potential.

13. Continued coordination on the broad array apple snail issues is needed; follow-up on all the recommendations in this Plan is beyond what one individual can do. Funding to support dedicated time towards Plan implementation would be appropriate to pursue.[112] At least one person is needed to work closely with legislators and agencies on policy.

<u>Aquatic pet industry sector/HDOA Quarantine Branch/DAR/UH CTAHR</u>
The aquatic pet industry was one of the earlier sources of introduction of the apple snail to Hawai'i in the 1970's. It was sold in pet shop to keep fish tanks clean. Since that time, many, but not all businesses have voluntarily stopped selling this pest.

1. There is still confusion among the aquatic pet industry in distinguishing between various species of apple snails. The industry would benefit from better information regarding *Pomacea canaliculata*.

    - Provide more information about the snail in general to improve understanding of why it is important to remove this snail from aquatic pet store lists
    - Coordinate trainings in the industry to improve identification of *P. canaliculata*.
    - Active outreach education to aquatic pet store customers by the aquatic pet industry. Develop a brochure describing apple snails and other tank cleaning snails (along with other aquatic pests) and how to properly dispose of them. Provide a copy of the brochure to every customer who purchases an aquatic pet or fish tank.
    - Improve public awareness of existing "return-a-pet" programs and increase the number of pet shops participating to all pet shops in the state. Provide pet shop owners and aquatic pet distributors with information on how to handle these pests.

<u>HDOA</u>
1. Apple snails are sold on the internet through numerous websites, many from Asia. Develop a means to monitor trade from these sites, including an e-response to aquatic pet websites that informs them it is illegal to mail or import the snails to Hawai'i. Alert and educate the Hawai'i Postal Service about this pest. Provide the Postal Service with a list of potential source addresses and businesses based on these websites that should be monitored closely.

[112] Collaboration with the Division of Aquatic Resources would be beneficial if federal or state funding is considered.

2. Assist in the dissemination of educational information to farmers and the general public. Update the HDOA website to reflect the information in this plan and create a link to the upcoming CGAPS apple snail webpage.

<u>CGAPS and ISCs</u>

1. Assistance with the development and dissemination of PSAs, flyers, events, presentations, and updates to the CGAPS apple snail webpage when it comes on board.

2. In collaboration with 'Onipa'a Nā Hui Kalo, develop an education and training program for community groups and consumers (ie. “Don’t Purchase a Pest – even if it’s on the menu!”).

<u>UH CTAHR</u>

1. Agriculture Extension Services staff are an important contact point for disseminating accurate information about the apple snail to a broad range of the public sector.

<u>Filippino and other ethnic community organizations</u>

The largest gap in invasive species education and outreach in the State of Hawai'i is in addressing the many ethnic groups within the state who do not speak English as their first language and are kinesthetic (tactile, sensory, experiential) learners. Often, the concept of an “invasive species” is missing within a culture and the language. The challenge of education outreach for these groups needs to begin from that perspective.

One shortcoming of the original HDOA flyers to the Filipino community was that it provided written material without other means of communication or follow-up. Those members of the community most likely to be apple snail consumers are also more likely to consider information through active talk-story. Face to face and interactive sessions will be a more affective method for outreach in this sector (C. Quemel, pers. com. 2006).

1. It will be critically important to involve Filipino leaders, particularly from women’s and farmers groups, cultural organizations, businesses and pastors at churches in order to create an effective outreach program in this community.

2. Existing non-English radio stations and television programs are an opportunity to disseminate information about the apple snail, the importance of taro in Hawai'i and other relevant topics.

2. Youth are the important link in changing attitudes and habits regarding the apple snail in the long term. Invasive species education in these communities and schools should have a strong emphasis on apple snails.

3. A bilingual education outreach coordinator who is familiar with the Filipino community, and the variety of organizations described above, and can communicate in at least one or more of the dialects present in the islands is imperative to reaching this group. This Plan

strongly recommends the creation of at least two positions, possibly located at the Ethnic Studies Department at UH Mānoa and at Maui Community College.

UH, DOE, Teachers and students

On Kaua'i and Hawai'i islands, teachers responding to apple snail discussions in their communities have asked to bring the issue into the schools so that students can also play a role in control efforts. Educating this student generation will have long lasting effects on future perceptions of this pest and continued allocation of resources towards protection of taro cultivation in Hawai'i.

In 2004, a "mini-curriculum" introducing the basic concepts of invasive species was developed and tested within the multi-cultural district of Pālolo, O'ahu.[113] The curriculum reinforced the key invasive species outreach messages developed by CGAPS. The interactive curriculum was also designed to bring the opportunity for education about invasive species directly into the home, where apple snails or taro may be on the dinner table.

A second, more indepth invasive species curriculum, using the apple snail as an example, has been developed and tested by UH graduate student, Justin Taylor, in conjunction with teachers at the UH Lab School and several other locations (J. Taylor, 2006).

1. A training for teachers who use these curriculums should be held to increase teacher knowledge and skills about invasive species in general and apple snails specifically, and encourage awareness and interest in protecting taro cultivation in Hawai'i.

2. Broaden invasive species presence in schools to include discussions and discovery of impacts to farming, the economy, community and family food resources, and cultural identity and survival. Feature apple snails as a key species in freshwater AIS awareness.

3. Develop a "challenge curriculum" for science teachers and their students, particularly for schools in taro growing communities, to encourage student creativity and push snail control thinking further outside the box of accepted wisdom in invasive species controls. Provide a prize for the most promising controls developed by youth. Follow up with researchers and taro farmers for in-field trials.

4. A recently installed display focusing on invasive species, and including apple snails, ran for three months at the UH Mānoa Hamilton Library (April – June 2006). It is recommended that support to update this exhibit and for travel to other UH campuses including UH Hilo, MCC and KCC and public libraries be found to extend the educational opportunity to other islands. A coordinated series of talks about invasive species would increase the impact of the information in the display.

[113] Developed by the Pālolo Invasive Species Swat Team project (PISST) under funding by the Hawai'i Invasive Species Council (see Appendix for example).

7.6 Research needs

A variety of research efforts have been undertaken to understand the snails biology and distribution. This Plan introduces and recommends follow-up on the most promising control strategies and new ideas that demonstrated realistic potential and gaps in our knowledge of the pest's behavior or weaknesses based on taro farmer recommendations and support. Some of the research recommendations described below can and should be tested on-farm by the taro farming community as well as by conventional scientific means. This applies, particularly to promising manual techniques for improved trapping and control.

Population size, behavior, distribution and mapping

1. Continued, regular monitoring and mapping of the spread of the snail is critical to adapting and improving control strategies. It is strongly recommended that additional survey be conducted to provide more accurate locational data, estimates on fallow taro lands, and other potential habitat types as described in this Plan.

   Field survey in 2004-2006 confirms the presence of apple snails outside lo'i kalo, however due to funding limitations and access issues, areas immediately upstream or outside of taro growing areas were not well investigated.

2. A study which documents and tracks the impacts of apple snails specifically on wetlands and endemic fauna in the state, including competition for food and breeding sites, and changes in nutrient cycling, across a range of infestation levels. This has received no funding or attention in the state or at the university.

3. Population behavior, density and spread pattern studies within densely vegetated wetlands will assist in developing appropriate control strategies for these types of sites around the state. At what level the snail population might crash, and what might trigger such an event, is a question that has no answer at this time.

4. Development of a database for farmers to record their observations of snail behavior and population cycles to assist in refining and coordinating the timing of applied control strategies in each ahupua'a and 'ili (smaller land districts within an ahupu'a).

5. Assess possible competition between native aquatic species and *Pomacea canaliculata* for food and spacial needs.

Control agents

1. Research trials into the efficacy of the promising organic fertilizer compound discovered by taro farmers on Maui **should be of highest priority**. Concurrently, tests on impacts to native aquatic biota should be conducted. This compound may provide significant hope for perennial wetland habitats and large lo'i systems.

2. Potassium chloride compound may be worthy of investigation for "big foot" response in mature snails and breakdown of shells in egg clusters. However, trials must carefully document labor and time requirements under real farm conditions in addition to efficacy, in order to determine if a spray application would be any more efficient than hand removal. Damage to taro plants, particularly the leaves, should be carefully monitored for lū'au growers.

3. HARC should be encouraged to continue pursuing current investigations into mugwort and yucca compounds. Realistic projections for the cost per acre and availability of these compounds are needed in addition to current trials. Effectiveness in large fields is particularly important.

4. Taro farmers and environmentalists strongly recommend further study on the accumulated impacts of copper sulfate to aquatic and marine ecosystems and organisms, including the long-term buildup of copper sulfate in lo'i soils, the uptake of copper sulfate by taro, the impact to lū'au producers, and to consumer health (particularly pregnant and nursing women and young children).[114]

Control techniques

1. Ducks. A number of research questions were raised in the development of the duck use guidelines.

   a. Better information is needed on the foraging preferences and habits of koloa and other native waterbirds and the times they are most active, along with a comparison study for domestic ducks under usage by taro farmers for snail controls. A detailed study on the contributions of domestic ducks to taro farming systems is recommended.

   b. Development of a successful sterile duck program (surgical or through breeding) in Hawai'i is an important option to regular domestic duck use for taro farmers in wildlife reserves. Guidance should be sought from Metzer Farms in California who produce a variety of duck breeds and specialize in Pekin breeds. They are familiar with the production of sterile ducks and the issues associated with domestic ducks, taro farming and koloa in Hawai'i. Prior to full development of a program, careful testing of this duck's behavior in taro patches by taro farmers and with their assessment is needed to determine if mullards would be too destructive to lo'i banks and taro plants and if they would be good snail feeders.

   c. Farmers recommend the management of domestic duck supplies for apple snail control be handled off-farm; for example, schools or projects with agriculture programs. Market analysis for the use of excess eggs and ducks in the fresh food

[114] Research on suggested untrialed control methods that appeared to have potentially limited impacts (based on an understanding of snail biology and behavior) or had a high risk for soil and water contamination were not considered appropriate for further study. One exception to this is made with copper sulfate to gain a better understanding of whether or not residual environmental impacts might need to be addressed from past use.

industry would provide such organizations with a means to fund projects after initial start-up and prevent expansion of domestic duck populations beyond farmer needs.

2. Fallow, cover and tillage. Continue to explore a variety of cover crops including those in the mustard family which have natural copper compounds (B. Schaffer, pers. com. 2004). Careful investigation should be conducted to determine any invasive tendencies of proposed covers before they are tested in the field. Any plant species that has been used in a country other than its place of origin for less than 15-20 years, should be considered a species with insufficient evidence to determine its ability to achieve critical mass and rates of colonization.

3. Better traps and barriers
   a. Comparative research on the effectiveness of a variety of bait treatments in combination with trenches along the inside edges of lo'i (a current strategy).

   b. Traditional lo'i kalo sometimes incorporated a loko i'a (inland fish pond) into the system. The potential of small, shallow ponds at the head and tail of lo'i systems to trap apple snails and prevent contamination further downstream is good. In-field trials should consider testing whether these ponds can be treated with organic compounds to suppress overall snail populations.

   c. Snails will avoid traversing surfaces that will dry them out or injure the foot. Land barriers such as fine pebble gravel or roughened metal strips to isolate infested fields within a system may be worth investigating. Field testing should include documenting realistic maintenance probability along with effectiveness.

   d. While the use of copper is prohibitive for most parts of the lo'i system, the design of effective, easy-to-maintain copper screens or barriers (or other repellant type barriers) at stream intakes should be pursued for those areas where lower stream reaches are infested with snails.

4. Investigation into compounds that might produce sterilization in apple snails has been recommended. In the more than 20 years that apple snails have been a pest globally, no research was found which investigates this possibility as yet.

5. Behavioral observations of snails in tanks suggest that high density populations of apple snails may turn on themselves if deprived of food and blocked from exiting a lo'i where low water levels are maintained and no water circulation occurs. Testing for this behavior should be a high priority to support control measures for lo'i systems that can not be dried out.

Monitoring and evaluation

1. A regularly applied control method which requires a subsidy to be affordable to farmers is not sustainable in the long run. One time inputs such as fencing, duck sheds or circumventing infested 'auwai should remain viable for a minimum of 5 years. Efficacy

of control techniques that require regular inputs should be carefully monitored for feasibility not only for large scale application in the field, but farmer affordability (in terms of time, labor and expense).

2. Efficacy of education outreach methods and materials is a must to keep outreach active, up-to-date, appropriate to a variety of audiences and changes in perceptions over time.

3. It is recommended that CGAPS partners monitor apple snail population growth and dispersal as part of its invasive species tracking and mapping efforts and include that in reports to its partners and to the legislature, in recognition of this snail's potential impact to lands far beyond taro farms.

4. Careful monitoring and evaluation of the suite of snail control mechanisms chosen by farmers and wetland managers should be an integral part of control efforts in order to refine techniques and improve results; this should apply particularly to the use of domestic ducks in Hanalei if they are used at this site.

Health

1. Monitoring for the presence of rat lungworm in apple snails throughout the state is recommended.

2. Vector control and monitoring of rat and mongoose populations in apple snail populated sites is requested, particularly for Hanalei, Waipi'o and Ke'anae.

3. As many as 60 percent of all taro farmers have evidence of contracting *leptospirosis* in their blood.[115] Taro farmers urge DOH to test all farmers in snail infested areas for the presence of *leptospirosis* and rat lungworm to establish a clearer baseline for current conditions. Regular follow-up monitoring should occur every two years through the first ten years of snail control efforts. Testing of taro farmers in non-snail areas should be conducted to provide a comparison and determine if there may be an increased risk for those farmers where snails are present.

Economics

1. It is difficult to convince agencies and businesses of the critical nature of the current situation with apple snails without the numbers to back it up. Further pursuit of the economic benefits of kalo to the state as described in the stakeholder section this Plan is recommended, particularly those aspects that are related to tourism and education.

2. The costs of recommended practices and the costs of not implementing those practices should continue to be pursued to increase the quality of existing information and further assist in decision-making for future invasive species control efforts.

[115] Bruce Anderson, former Director, DOH (C. Reppun, pers. com. 2006).

7.7 Policy

A number of federal and state laws exist related to the transport and introduction of invasive species in Hawai'i. A full discussion of those policies is available in the *State of Hawai'i Aquatic Invasive Species Management Plan* (Schluker 2003; Chpt 3 Existing Authorities and Programs). The AIS Plan also provides a discussion of agencies that address the issue of aquatic invasive species. One of the primary policy action items in the AIS plan is a review of "laws and regulations governing AIS in Hawai'i for gaps and overlaps" with an outcome of recommendations to improve state capacity to protect Hawaii's waters (AIS Plan; Strategy 7A). A critical missing issue in this discussion is an assessment of the laws and rules of various state agencies for conflicting policy and programs between agencies and within individual branches of each agency. It is here that apple snails first slipped through the net of prevention and eradication. The HDOA found itself first permitting the snail as an economic enterprise (for the pet industry) on the one hand and then tasked with control efforts for an invasive species on the other.

The *Statewide Strategic Control Plan for Apple Snails (Pomacea canaliculata) in Hawai'i* also finds that existing federal and state laws have not been applied to the issue of apple snail control to their best possible outcome. In the case of continuing to allow and support the development of economic enterprise around the apple snail after the year 2000 (see below, the *Plant Protection Act*), the State of Hawai'i may have played a conflicting role in the presence of apple snails within the state. It also suggests the State of Hawai'i has federally backed authority to completely prohibit the raising, sale and distribution of apple snails on every island, if it chooses.

General

1. This Plan strongly recommends that state and federal agencies work closely the Attorney General's Office, EarthJustice,[116] and 'Onipa'a Nā Hui Kalo to proactively close the gap in existing statutes and administrative rules that inhibit the ability of government agencies to act efficiently or affectively in regards to *Pomacea canaliculata*. In particular, increased protection for taro farmers and lo'i kalo from this invasive species is urgently needed.

Federal mandates

Executive Order 13112 (1999) on Invasive Species (64 Fed. Reg. 6193) not only instructs all federal agencies to address invasive species concerns but also to "refrain from actions likely to increase invasive species problems" (Schluker 2003; p3-3). This suggests federal dollars in support of programs which may have compounded and contributed to further spread of the snail, whether directly funded or indirectly funded through the State, should be terminated.

[116] Earthjustice Legal Defense has represented taro farmers for many years in water issues with the State of Hawai'i. Their expertise in issues that taro farmers face in trying to make a livelihood, in the interpretation of rules and laws affecting taro farming, and EPA regulations is an important asset to the big picture of statewide control efforts for this pest.

The *Plant Protection Act (2000; 7 U.S.C. 7701 et seq.)* gives the USDA the authority to "hold, seize, quarantine, treat, apply other remedial measures to destroy or otherwise dispose of any plant, plant pest, noxious weed, biological control organism, plant product, article or means of conveyance that is moving (or has moved) into or through the United States or interstate, if USDA considers it necessary in order to prevent the dissemination of a plant pest or noxious weed that is new to or not known to be widely prevalent or distributed within or throughout the United States. This authority extends to progeny of prohibited items moved in violation of the PPA" (Schluker 2003; p3-4).

What is useful in this Act for serious control and eradication efforts for apple snails is the following:

> [The Act] also authorizes USDA to order an owner, or an agent of the owner, of a plant, biological control organism, plant product, plant pest, noxious weed, article, or means of conveyance to treat, destroy, or otherwise dispose of those items. In addition, when a State is unable or unwilling to take the necessary action to prevent the dissemination of a plant pest or noxious weed, the Secretary has the authority to declare an extraordinary emergency and take the actions described in this paragraph within a State (i.e., when interstate movement is not involved)." (Schluker 2003; p3-4)

Federal agency and program policy

USDA– Natural Resources Conservation Service

1. Currently, Wildlife Habitat Incentives Program (WHIP) Shallow Water Management Practice 646 is the only supportive practice to assist taro farmers in control of this invasive species. Updating the USDA-NRCS invasive species lists for the Environmental Quality Incentives Program (EQIP) to include *Pomacea canaliculata* will potentially make EQIP funding available specifically to control this pest, particularly in fallowed wet fields. This would support taro farmers without having to commit lo'i kalo to endangered waterbird habitat, which comes with additional constraints that not all farmers can bear.

USFWS

1. There is an urgent need to positively address issues related to apple snail conditions in state and federal wetlands and wildlife refuges (Section 6.4 Perennial wetlands in this Plan) and for federal level support and assistance to taro farmers adjacent to these sites in relation to the control recommendations described in the Plan. An MOA or other agreement may be needed to allow a domestic duck program as outlined in this document. Many taro farmers have already expressed willingness to assist USFWS in monitoring for avian diseases and feral birds. A programmatic Safe Harbor agreement may be useful to protect farmers where use of lo'i kalo by koloa are a concern.

State statutes and rules

At present, HAR §4-69A lists *Pomacea canaliculata* as a species for control or eradication. Only someone with a research permit can transport the snail. However, the rule does not address the possession or propagation of this species formally or informally for aquaculture purposes.[117] The snail is allowed live or processed for sale in local markets from on-island sources.

HAR §4-9-5 and 4-54-2 relating to the Aquaculture Loan Program and Marketing and Consumer Services Eligibility for Product Promotion Assistance respectively provide no language to prevent or restrict assistance to enterprises based on the production or promotion of a product whose sole source is an invasive species defined by HDOA as a pest.

HAR §4-72-8 Plant Intrastate Rules Restrictions on Harboring, Rearing or Breeding of Pests cites only those pests defined under HRS §150A-2 which is an importation and transport rule and does not appear to tie restrictions to DLNR or HDOA invasive species lists.

HRS. §197-3 states that "No species of aquatic life or wildlife may be deliberately introduced by the department into the State of Hawai'i, whether it be from outside the State into the State or from one area within the State to another area in the State, unless the introduction is recommended by the DLNR and authorized by its rules." This rule applies to state agencies and not private individuals. However, HAR §195D Conservation of Aquatic Life, Wildlife and Plants provides for the protection of threatened and endangered species and their supporting habitats by making it unlawful to harm such species. This includes the deliberate introduction of aquatic invasive species into freshwater bodies in the state.

HAR §13-124 Indigenous Wildlife, Endangered and Threatened Wildlife and Introduced Wild Birds, cites with respect to injurious wildlife (listing apple snail), no person shall, or attempt to: (1) release injurious wildlife into the wild; (2) transport, take to islands or locations within the State where they are not already established and living on the wild; (3) export any such species, or dead body or parts thereof, from the State. This rule applies to intra- and inter-state movement of the apple snail whether alive, in a processed form, or parts. Because the snail is widely established, movement between islands or districts within islands would not be illegal in many locations under this law, unless it also would result in injury to wildlife.

<u>HDOA, DLNR, DAR, DOH</u>

1. While the release of apple snails in the wild is illegal in the state, ironically, the raising and sale of the species is not. The continued presence of permitted apple snail enterprises in Hawai`i sends a conflicting message to the tireless individuals involved in invasive species efforts throughout the islands. To the best knowledge of this Plan, there are only two to three permitted facilities still raising apple snails in the state, with an unknown number of subsistence level unmanaged enterprises and exchanges occurring annually. It is not clear where permits originate and what agencies have jurisdictions for allowance of apple snail enterprises and suggests the need for across agency communication. The DOH assesses a food industry business (escargot) on the basis of health and safety

[117] This is distinctly different from the uncontrollable presence of apple snails in farmer's lo'i, but refers specifically to those individuals who deliberately introduce, manage or maintain the snails on their own or other's property for the purpose of regular harvest and sale without the intent of eradication.

regulations but has no regulations regarding the dependence of an enterprise on the presence of an invasive species.

While it is not favorable to close a legitimate business, the state has acted in a similar manner in other situations, ie. encouraging voluntary compliance for the removal of invasive plant species from nurseries and plant outlets by the landscape and nursery industries; the condemnation with fair compensation of properties for conservation, rights of way or the building of public facilities; and even the cancellation of developments (ie. Kakaako) or bans on industry practices (ie. bill boards) that compromise or cause detriment to the view planes, open spaces, sites, practices, experiences and things which make this state unique. Taro and lo'i kalo surely qualify as such.

Taro farmers recommend that the snails be banned, across the board, as an economic opportunity in Hawai'i. The federal Northwest Hawaiian Islands phase out of bottom fishing can be an example of how this might occur. Farmer observation is that where money can be made, there will never be a reason to completely eradicate snails from an area. This is apparent from past experience with pest-for-profit efforts and the numerous Filipino farmers who continue to raise and distribute the snail in seemingly every available open waterbody, including farmer's lo'i, open ditches, 'auwai and ponds with little regard for the impacts to their neighbors.

2. National law currently prevents the expenditure of federal funds on invasive species (Executive Order 13112). The State of Hawai'i would send a strong message and set a powerful national precedent by creating matching legislation for state and county funding. This would prevent a re-occurrence of the conflicts created by the apple snail pest-for-profit program. This is also recommended for the Small Business Incentive Program and similar incubator projects such as MEO, many of which receive federal, state and county funding. The above mentioned administrative rules regarding enterprise loans and marketing assistance need to be revised to reflect this concern. If future invasive species use proposals make sense, then it may be better to take the precautions to make them the exception than the allowable rule.

State agency programs and policy

HDOA and DLNR

1. Policies within HDOA which allow pest-for-profit programs as described above should be revisited and rules updated to prevent what happened with apple snails from happening with the next invasive species. Agency review of existing evidence of invasiveness from other countries should weigh heavily in decisions to support or deny permits for new species.

2. In order to protect existing snail-free zones, and fully support control efforts, farmers urge that the state legislature, HDOA, DOH, DLNR and CGAPS partners support a complete ban on the raising, transport or sale of apple snails in the State of Hawai'i.

3. Until such time as the legality of raising and selling apple snails can be properly addressed, assistance from the HDOA Plant Quarantine Branch is requested to find and inspect registered and unregistered apple snail farms (formal or informal) for poorly designed enclosures and adherence to recommendations for improved containment.

4. DAR's statutory authority to prohibit, fine and jail persons who deliberately dump non-native aquatic organisms into any waters of the state, needs a bigger spotlight in outreach education, particularly to the Filipino community in the case of apple snails.

<u>DOH</u>

1. The potential for apple snails to become a vector for disease transfer between rats, snails, prawns, and humans is high. The opportunity for a rise in *leptospirosis* incidents increases with a rise in frequency of cuts from snail shells.

   Currently, rats in the state are tested for presence of rat lungworm. The presence of a large food source for rats and mongoose (live and composting snails) indicates the need for more precise monitoring. Occurrences of the disease (*Angiostrongylus cantonensis)* in humans is now reportable by the health community to DOH (2005).

   a. Regularly test and monitor apple snail and rat populations for presence of *Angiostronglylus cantonensis*, with particular attention to Hanalei and Waipā, Kaua`i; Ke'anae and the Waihe'e to Kahului area, Maui; Waipi'o, Hawai`i, Waialua-Hale'iwa, Kawainui Marsh, and Punalu'u area, O'ahu.

   b. Taro farmers report significant delays between the time they see a doctor for suspected *leptospirosis* infection and treatment with antibiotics. Lab diagnosis can take from 6 to 10 days to determine the presence of the infection; enough time to cause serious repercussions to physical health. Delays between diagnosis and treatment in several incidents over the last few years have almost cost taro farmers and several children from farming families their lives. Improved response by doctors and labs is seriously needed.

      Monitor and evaluate physician response to treatment of patients with potential for *leptospirosis*. Request doctors ask patients " have you been in a taro patch recently?" and "did you receive any cuts from snails while in the taro patch?" Recommend antibiotics in cases where the answer to these questions is 'yes'.

<u>All agencies</u>

1. Support for apple snail control funding outlined in this Plan is requested from HDOA, DLNR DOH , and the HISC in the form of agency recommendations and requests for funding to the legislature, the governor and federal agencies such as USDA, USFWS and EPA.

2. Formal adoption of this Plan across state agencies to allow the recommended actions in the Plan to become a clear part of agency work plans and budgets.

Policy with funding mandates and rewards/incentives

Most taro growing areas are located within the lowest reaches of streams, bottom lands and estuarian flats. The *Coastal Zone Management Act of 1972 (CZMA; 16 U.S.C. §1451 to 1465)* suggests resources can be directed towards greater protection of freshwater resources through this Act.

The federal *Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (NANPCA; Title I of P. NO. 101-646, 16 U.S.C. § 4701 et seq.)* was established to support the development of control plans for noxious aquatic invasives by states. Federal grants are "authorized to states for implementing approved management plans, with a maximum Federal share of 75% of the cost of each comprehensive management plan" (Schluker 2003).

<u>State and County</u>

1. Tax breaks can provide rewards and alleviate burdens for limited resource families. Three tax breaks are recommended:
   - for farmers and landowners combating invasive species;
   - for taro farmers who incur damage due to apple snails; and
   - for landowners or lessees who improve the health of freshwater habitat by restoring lo'i kalo and wetlands.

<u>Hawaiian agencies</u>

1. Many of the beneficiaries of QLCC and OHA, Alu Like, DHHL and other Hawaiian agencies are also taro farmers. These agencies are requested to consider how the various programs, incentives and resources within their organizations can support the recommendations in this Plan and collectively evaluate and strengthen existing supports to taro farmers.

2. For Hawaiian families loss of kalo as a resource due to apple snails (or any other cause) is a health and welfare issue that should be of serious concern to the Hawai'i Department of Health, Alu Like and the Office of Hawiian Affairs. These agencies have an opportunity to positively influence the outcome of resource allocations for apple snail control at many levels.

Jurisdication issues

Issues of jurisdiction for the care and management of wetlands by federal, state and private entities in the Hawai'i (along with a lack of staffing and resources) have hindered control efforts and fostered a habit of passive management over many decades. This is changing; however, despite current efforts to control and remove invasive species (primarily plants) in some wetlands around the state, no efforts have been directed specifically at reducing apple snail populations. Irrigation ditches, water drainages, ponds and other waterbodies are even more marginally considered. The range of private and public sector agencies include the various companies that own the ditch systems, private land owners, the Counties, DLNR, Department of Transportation, DOH- Clean Water Branch, USFWS, and Army Corps of Engineers among others.

1. Pest control plans and implementation for all applicable agencies should be updated to include apple snail management based on the actions outlined in this Plan. It is strongly recommended that future invasive species control efforts for these properties include active suppression of apple snail populations in perennial wetlands, irrigation ditches and other waterbodies within the control of state, federal and private landowners and/or managers.

2. Landowners have a degree of responsibility that is supported by law regarding negative impacts to adjacent parcels, crops or families that originate on their property.[118] Continual re-infestation of taro farms by apple snails from these sites contributes to crop loss and increased labor costs for controls annually. Federal, state and private landowners are strongly encouraged to work with farmers to reduce snail populations on these lands.

[118] For example, a landowner including the state or county is liable for a tree that poses a hazard to a neighbor's home or whose roots threaten to disrupt fences and foundations under County ordinances. The owner of a parcel where erosion originates is liable for damages to adjacent lands and waters under state law.

8. Timeline

Year 1

1. Convene a series of discussions with taro farmers, state and federal agencies to:
   - Brief agency heads and staff on apple snail status and issues
   - Begin the process of systematically addressing the recommendations and actions outlined in this Plan.
   - Gain commitments from agencies and organizations to take on the various tasks outlined in the Plan.
   - Focus efforts where they are most needed by taro farmers and wetlands

2. Fund a position to coordinate activities, distribute information, and consistently move the Plan forward for a minimum of five and up to ten years.

3. Work closely with legislators and agencies to review and change key laws, rules and policies and to develop a dedicated plan for funding implementation of the Plan. Initiate requests for federal crop disaster relief and invasive species control funding.

4. Design a coordinated five year education outreach program for apple snail control efforts to all groups outlined in this Plan, including the taro farming community, and begin implementation. Find a counterpart within the Filipino community to mirror outreach efforts there. Complete presentations to all relevant federal, state, and county agencies, and invasive species field crews within the first year.

5. Fund a coordinator position to assess the condition of existing Hawaiian variety taro collections and develop protocols and tracking mechanisms for a long-term dissemination program; and three tech/apprentice positions to assist in field propagation for key collections.

6. Develop a curriculum for a Master Taro Farmer training program and implement at least one training in the first year.

7. Develop and implement a rapid response plan for newly infested areas in coordination with DAR's Aquatic Invasives Swat Team, the ISCs, and HDOA Quarantine Division. Implement pro-active protection actions for existing snail-free zones and monitor bi-annually for success.

8. Begin development of a coordinated and balanced apple snail control program with managers of protected wetlands around the state.

9. Determine the template for future field survey and implement GIS mapping that matches invasive species tracking databases used by DAR.

10. Work with taro farmers and partners to assist them in developing individual control efforts and landscape level control design and implementation strategies based on localized conditions.

11. Monitor apple snail populations, track control efforts and their impacts.

Year 2

1. Assess historical flooding patterns in the most affected valleys. Facilitate coordination and implementation of landscape level snail control efforts with landowners, agencies and farmers.

2. Implement improved hydrological flows and hau bush cleanup along the river in Hanalei Valley.

3. Domestic duck projects implemented on all islands with education for BMPs and monitoring in place.

4. Crop disaster relief funding in place to support implementation of on-farm control recommendations.

5. Continue to work closely with legislators and agencies to review and change key laws, rules and policies and to pursue coordinated funding for the Plan and for federal crop disaster relief for taro farmers.

6. Initiate research from the list outlined in this Plan, including in-lab treatments of the most promising methods. Parallel efficacy trials with impact trials on native species.

7. Implement the second Master Taro Farmer trainings in coordination with the expansion of taro collections. Begin initiatives to return varieties to their places of origin.

8. Continue education outreach to all described groups, with a strong focus on the Filipino community and other cultural and consumer groups. Evaluate program effectiveness and adapt methods accordingly.

9. Work with taro farmers and partners to assist them in developing individual control efforts and landscape level control design and implementation strategies based on localized conditions.

10. Monitor apple snail populations, track control efforts and their impacts.

Year 3

1. Continue to implement landscape level wetland and lo'i kalo systems control efforts in major taro growing areas. Implement improved back-flooding controls for Hanalei Valley.

2. Continue to work with taro farmers and partners to assist them in developing individual control efforts and landscape level control design and implementation strategies based on localized conditions.

3. Continue to work closely with legislators and agencies to coordinate and implement the Plan throughout the remainder of the next ten years.

4. Implement the third Master Taro Farmer training in coordination with the second expansion of taro collections. Continue initiatives to return varieties to their places of origin.

5. Continue research from the list outlined in this Plan. Move in-lab treatments to the field. Continue impact trials on native species. At least one organic control agent available for distribution to farmers and wetland managers for field treatment.

6. Continue education outreach to all described groups. Evaluate program effectiveness and adapt methods accordingly.

7. Monitor apple snail populations, track control efforts and their impacts. Evaluate the degree of accomplishment in relation to the control plan; track and map any changes in snail population size and location. Update these maps annually.

8. Coordinate evaluation among taro farming communities and wetland managers to improve efforts.

Year 4

1. Continue to implement Master Taro Farmer trainings in coordination with the third expansion of taro collections. Continue initiatives to return varieties to their places of origin.

2. Continue research from the list outlined in this Plan. Continue to expand in- field testing, evaluate and if appropriate move to next steps in the process.

3. Continue education outreach to all described groups. Evaluate program effectiveness and adapt methods accordingly.

4. Continue to work with taro farmers and partners to assist them in developing individual control efforts and landscape level control design and implementation strategies based on localized conditions.

5. Monitor apple snail populations, track control efforts and their impacts.

Year 5

Most actions by Year Five will be a continuation of previous years with refinement and adaption as efforts are mapped and assessed. Until agency and individual project specific action details are developed, only general recommendations can be made for the timeline.

1. Multiple choices for organic control agents available to farmers and wetland managers for field treatment.

2. Continue with the expansion of taro collections and the recovery program.

3. Continue education outreach to all described groups. Evaluate overall outreach effectiveness and determine next steps.

4. Work with taro farmers and partners to assist them in developing individual control efforts and landscape level control design and implementation strategies based on localized conditions.

5. Monitor apple snail populations, track control efforts and their impacts. Evaluate the degree of accomplishment in relation to the control plan.

6. Coordinate evaluation among taro farming communities and wetland managers to improve efforts.

Year 6-10

1. Continue with the expansion of pro-active prevention and protection programs including expansion of taro varieties recovery programs.

2. Continue education outreach to all described groups. Update and adapt materials and efforts as necessary.

3. Continue to work with taro farmers and partners to assist them in developing individual control efforts and landscape level control design and implementation strategies based on localized conditions.

4. Monitor apple snail populations, track control efforts and their impacts. Evaluate the degree of accomplishment in relation to the control plan in year 7 and 10.

5. Coordinate evaluation among taro farming communities and wetland managers to improve efforts every year.

8.1 Collaboration

If the outlined actions in Section 6 are to bear fruit, a variety of resources and partners are necessary. Farmers can not accomplish these tasks themselves. 'Onipa'a Nā Hui Kalo, other taro associations, and taro farmers statewide request that USFWS, USDA, NRCS, DLNR, DOFAW, DAR, DOH, DOT, DHHL, HDOA, HISC and it's subcommittees, CGAPS, ISCs along with county, state and federal legislators, and the Governor of Hawai'i, along with other federal, state, public and private agencies and organizations, landowners and businesses at the policy, research, and action level *who have the authority, the will and the potential to positively contribute to this effort* to join them as partners in controlling *Pomacea canaliculata*.

The consideration of who is best suited to what roles in control efforts includes each potential partner's own perception of where they are most able to contribute based on mandated and allowable activities, staffing, interests and resource availability. This helps to identify gaps in covering the work outlined by this Plan and the need to find additional partners. Each of the entities listed below should be part of assisting in educational outreach. It is not possible to list all the potential partners that might possibly come together for this effort.

USFWS is the most appropriate agency to conduct research on the foraging preferences and patterns of koloa and other waterbird species. In addition, this agency's participation is critical in finding long term strategies that support both taro farmer survival and improved conditions in wetlands in Hawai'i. They are also currently one of the agencies responsible for monitoring avian diseases that may enter the state.

HISC and CGAPS were created as a mechanism for opening the doors to collaborative invasive species control and prevention and speeding up response time at a legislative, agency and field levels. The Council, with support from the many CGAPS partners, has the ability, if it chooses, to get this Plan adopted and funded, to steward and support legislation, to direct each of its agency seats to implement those portions of the Plan that fall into their jurisdiction, and to help find solutions where gaps in jurisdiction or leadership occur.

DLNR and its divisions have many roles to play in relation to the Plan. DAR is the one of the appropriate lead agencies, along with its many partners, to facilitate the attraction of federal and state resources to this control effort. Its administrative rules also designate it as the coordinating agency for tracking the spread of the aquatic species and enforcement.

HDOA has identified itself as best suited to the role of active suppression with a focus on in-field controls for taro patches. They are the appropriate agency to assist in the acquisition of funds for promising controls research and for federal crop disaster funding.

ACOE may be one of the agencies able to assist in the assessment of historical and present-day hydrology patterns for large wetlands in the state.

DOH in addition to the role this agency has to play in addressing health related issues surrounding the apple snail, the department's Clean Water Branch 319 Funds program would be an exciting partnership for ahupua'a level snail control efforts.

DOT has jurisdiction over a number of irrigation waterways that need to be cleaned and monitored for the presence of apple snails.

ISCs (each island and statewide) have volunteered to assist in outreach education. In addition this group should be a part of rapid response planning and response, as support to the newly formed DAR aquatic team.

Some UH CTAHR researchers have stated a willingness to collaborate with taro farmers on some of the above outlined research needs if funding is made available. The university has an important role to play in outreach education, particularly within the various ethnic farming communities in the state.

Office of Hawaiian Affairs, Queen Lili'uokalani Children's Center, Alu Like, Queen Emma Foundation, Department of Hawaiian Homelands, Bishop Estate/Kamehameha Schools all play important roles in perpetuating Hawaiian culture and helping Hawaiians to remain on the land. There could be no better role for these agencies in this effort than to support the protection and perpetuation of traditional taro varieties for the future, or to protect the health of the Hawaiian community from this pest, for kalo is Hāloa, the first kanaka maoli of the land.

The National Tropical Botanical Gardens, Waimea Arboretum, Lyon Arboretum and Maui Nui Botanical Garden have all played a role in establishing small gardens of traditional Hawaiian taro varieties at one time or another during their history and renewed efforts have begun to improve existing collections. Lyon, in particular, has a tissue culture laboratory. Each of these gardens, along with UH CTAHR Agriculture Extension staff would be welcome partners in increasing the availability of traditional taro varieties on each of the main islands.

US Pacific Basin Agricultural Research Center, Hilo has expressed interest in collaborating on research related to the use of domestic ducks as apple snail control, including the efficiency of various breeds. A good match for this interest is a partnership with USFWS for comparative koloa foraging studies.

Hawai'i Visitors Industry (DBEDT and HVB) clearly benefits from the presence of taro in Hawai`i daily. If even $0.01 was set aside from every dollar earned through the room tax or sight-seeing tours every year significant funding would be become immediately available to combat apple snails. HVB has begun to contribute to the preservation of natural resources in a limited way. It is recommended that the industry make a serious commitment to those things from which it receives such invaluable returns devoid of pressure on taro farmers for increased access to lo'i kalo for visitors.

American Savings Bank has taken the step of claiming kalo as its logo and marketing engine. In support of preserving the source of its inspiration and image, the Bank is encouraged to become a funding partner in this action plan.

Hawai'i State Legislature should be a staunch partner in the fight to preserve taro culture in the Islands. All state and county Representatives and Senators, along with all County Council members, are called on to support and steward bills through the legislature that will provide funding for action and change policy where policy needs to be changed.

The Governor of Hawai'i is needed to sign and support the various bills and budget allocations necessary to control apple snails in the state and protect wetland agriculture and wildlife habitat from a repeat of this scenario. The Governor's Office is requested to support and steward requests to the federal level for assistance and resources.

Looking to the future - reducing taxpayer costs for invasive species control programs

Self-sufficiency is often seen as a characteristic of the taro farming community; in reality, interdependence is the more distinguishing trait. This attribute should also shape the gathering of resources for apple snail control efforts so that no one agency or sector of the population is over-burdened by the costs of control. Resources shared across agencies and community groups will translate to fewer repeated costs. Collaboration will support simpler, smoother transitions and reduce overall costs.

It is clear that federal, state and county funding can only take invasive species control efforts so far. And, whether funding comes from the federal sector or the state, it still originates from the same pocket - taxpayers. The in-kind contributions of the community sector towards invasive species control have increased annually even as the availability of private sector funding continues to decline nationally. The potential contributions of the business sector have yet to be tapped, but needs to be considered beyond the boundaries of the state where the pool of businesses is small and where giving is already substantial. Making the issue of invasive species, and the apple snail specifically, relevant to global, national and local businesses means a stronger focus on how these species impact the bottom line across a variety of trades that do business in Hawai'i. If one out of five new visitors to the state donated just one dime towards keeping taro alive in Hawai'i; a sizable amount of apple snail control efforts would be paid for annually.

Patented products that may result from research into the promising organic compound described in Section 5.25 should clearly include the taro farmers who helped to discover its properties and the company who owns the compound. A portion of profits (if products are brought to market) could be directed back into establishing a self-supporting fund for ongoing apple snail control efforts. Other work on control products are also encouraged to contribute to a self-sufficient invasive species control program for the snail whether through a portion of royalties or making products available and affordable.

Dedicated county, state and federal allocations in the first five to ten years will allow partners to begin to immediately address the most important control efforts. It will also buy time for partners to implement a strategic search for private sector contributions and other actions that will support long-term program self-sufficiency.

9. Resource needs

The high costs needs of this estimated budget are a direct result of 20 years of resource neglect. The estimates do not make a distinction between federal, state or private dollars and do not include in-kind or existing resources that contribute towards accomplishing the above recommendations and would reduce actual dollar needs. It is extremely general in nature with line items only at the large topic level. Refined budgets are only possible once partners agree to actions and coordinate and assess real resource needs for implementation. Figures below represent best estimates based on similar past projects, a few known costs, and the assumption that most but perhaps not all of the recommendations under each section would be funded.

Budget Detail:

Action	Estimated Budget: **YR 1-3**	Estimated Budget: **YR 4-5**	Estimated Budget: YR **6-10**
1. Pro-Active Prevention			
A. Protecting snail-free districts	$150,000	$100,000	$250,000
B. Protecting and preserving traditional Hawaiian taro varieties, secure huli resources, cultural practice, and lifestyle choices	$450,000	$250,000	$250,000
2. On-Farm BMPs			
A. Eradication on new sites	$250,000	$200,000	$250,000
B. Integrated practices for infested farms	$1,500,000	$1,500,000	$1,500,000
C. Domestic ducks	$100,000	$50,000	$50,000
E. Landscape and ecosystem level strategies	$1,500,000	$1,500,000	$1,500,000
4. Perennial Wetlands	$2,000,000	$1,000,000	$2,000,000
5. Education outreach	$250,000	$150,000	$150,000
6. Research needs			
General	$250,000	$250,000	$250,000
Organic compound	$350,000	$250,000	$250,000
Economic studies	$75,000	$50,000	$50,000
TOTAL	$6.875MIL	$5.3 MIL	$6.5 MIL
Time frame	**3 Years**	**2 Years**	**5 Years**
Avg per year	$2.29 MIL	$2.65 MIL	$1.3 MIL

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Personal communication:

Only those individuals who were specifically quoted or referenced in the Plan are listed here. The list of taro farmers, cultural practitioners, organizations, agency staff and others who have contributed to the content of this document surpasses well over 100 people. To all of you, mahalo nui loa.

Paul Achitoff	Earth Justice	April 2006
Arlene Buchholz	DOH	June 2006
Jeff Burkett	US Fish and Wildlife Service	25 April 2006
Robert Cowie	UH Center for Conservation Research and Training	2004-2006
Scott Crawford	Kïpahulu `Ohana	28 July 2005
Arleone Dibbon-Young	Moloka`i	7 October 2005
Rodney Hariguchi	Hanalei Taro Association	2005-2006
Skippy Hau	DLNR - Department of Aquatics, Maui	14 Dec 2004; 12 April 2006

Mel Jackson	HARC	12 April 2006
Nalei Kahakalau	Kanu o ka `Āina Charter School	Oct 2005
John Lind	Taro farmer, Kïpahulu `Ohana	April 2006
Nilton Matayoshi	Department of Agriculture	11 Feb 2005
Susan Miyaska	UH Hilo	15 July 2005
Christine Quemel	UH Women's Center	13 April 2006
Charlie Reppun	Taro farmer	28 April 2006
Bob Schaffer	Soil Culture Consulting	10 Oct 2004
Michael Silbernagle	Campbell National Wildlife Refuge	5 May 2006
Chris Smith	NRCS	April 2006
David Smith	DLNR-DOFAW O'ahu Office	5 May 2006
Clyde Tamaru	UH SEA GRANT	28 Oct 2005
Justin Taylor	UH CTAHR	Nov 2005
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Lyle Wong	HDOA	14 Oct 2004

Appendix A:

Guidelines for use of domestic ducks as a component of apple snail control in lo`i kalo

A limited number of taro farmers have benefited from the use of domestic ducks in control of the apple snail *Pomacea canaliculata* since 1990. Those farmers who have integrated the ducks into snail control efforts realize fewer crop losses than those without access to ducks; often less than five percent (Statewide Strategic Control Plan for Apple Snails in Hawai`i, 2006). Taro farmer interest in improving the effectiveness of this snail control technique and concern for the protection of the koloa, or native Hawaiian duck (*Anas wyvilliana*) which can hybridize with feral and domestic ducks in the Mallard family, led taro farmers to open a dialogue with state and federal agencies.

On January 25, 2005 a meeting was held with taro farmers, a commercial duck breeder, a snail specialist, avian and wildlife biologists and invasive species specialists from the Hawai'i Department of Agriculture Plant Quarantine Branch (HDOA), the Department of Land and Natural Resources Division of Forestry and Wildlife (DOFAW) and U.S. Fish and Wildlife Service (USFWS) with the purpose of sharing information and answering questions regarding native/domestic duck issues and policies in Hawai'i. The meeting was initiated by 'Onipa'a Nā Hui Kalo, a statewide organization of taro farmers. Neither the meeting, nor the following document, where required by any agency, nor was it the result of a Section 7 consultation. Rather, taro farmers were looking to find better solutions to the current situation regarding *Pomacea canaliculata*, an invasive apple snail that has decimated the taro crop. Farmers also hoped to communicate the magnitude of the snail problem, to create opportunities for support and enlist the help of state and federal agencies in control efforts.

One result of that meeting was an informal agreement between taro farmers and agencies to develop a "best management practices" guideline for use of domestic ducks as part of apple snail control efforts that would benefit both taro farmers and protect the endemic koloa (*Anas wyvilliana*). Discussion with current users of domestic ducks in Kaua'i, Maui and Hawai'i produced a draft which was reviewed by the broader taro farming community and participating state/federal agency specialists. The final document outlines both BMPs and "next best alternatives" as farmers struggle to work with existing resources. The intent of this document is to encourage farmers and wildlife specialists to work together towards being able to fully implement these guidelines without increasing burdens on taro farmers or endangering koloa; however, it also recognizes that not all the BMPs described in this document may be possible to implement for all farmers due to limits in existing resources on each islands.[119] All farmers are encouraged to implement these guidelines to the maximum extent possible.

This document is part of an indepth statewide strategic plan for apple snail control developed "from the ground up" by taro farmers throughout the state (Levin and 'Onipa'a Nā Hui Kalo 2006). For a more thorough discussion of snail impacts, see the complete document.

[119] The limited availability of Pekin ducks and the complete lack of sterile ducks in Hawai'i are two examples.

Background

Kalo (taro) is the most culturally significant agricultural crop in Hawai'i. It was one of the plants Hawaiians brought with them when they first arrived by canoe to these islands. Historically, thousands of acres were cultivated; today, roughly 500 acres of kalo lands are actively maintained, 235 of those acres are located in Kaua'i where the majority of taro and poi are produced for the state. Taro farming provides both primary and secondary income and forms a significant portion of food budgets for taro-farming families (Levin *et al*. in press). While economically it is considered only a minor crop by the Hawai'i Department of Agriculture, the benefits of taro and lo'i kalo (wetland taro systems) to the state are widespread. The taro-growing areas of Hanalei, Kaua'I; Ke'anae, Maui; Waipi'o, Hawai'i and Hale'iwa, O'ahu are the core of the commercial taro industry. Kalo is recognized as elder brother to the Hawaiian people and plays an important role in cultural identity, spiritual wellbeing, and the lifestyle of those who choose to plant it. It is this sacred plant which resides at the piko (center) of Hawaiian culture and agriculture and makes Hawai'i unique in all of Polynesia.

The apple snail *Pomacea canaliculata* is a highly aggressive invasive species that threatens the survival of taro culture in Hawai'i in a way that no other disease or pest has ever done before. Almost 11,000 acres of wetlands and other waterbodies (of which taro farms make up less than 5%) are also at risk or already invaded by this species, making the issue of apple snail control one that concerns of every state and federal conservation agency in the state.

This particular apple snail species is present on all main islands except Moloka'i, Ni'ihau, and Kaho'olawe. It thrives best in perennial wetland areas which coincide with the largest taro producing areas. The species is characterized by rapid development and extremely high rates of reproduction which increase in warmer weather and slow, shallow waters. It consumes a wide variety of vegetative matter and debris, but may have some preference for taro in Hawai'i. High densities of snails have the capacity to reduce the floral and faunal diversity in wetlands significantly (Carlsson et al. 2004). It can breathe both on land and underwater and survives long drought periods by burrowing into the mud where it hibernates for many months. The ecology of the snail is described in detail the *Statewide Strategic Control Plan for Apple Snail (Pomacea canaliculata) in Hawai'i* (2006) and in R. Cowie (2002). Crop loss due to apple snails has been estimated at 18-25% (HAS 2004; Levin *et al*. in press). Control efforts have increased labor by almost 50%. (Levin et al. 2006 in draft). Apple snails are a known vector for disease transmission to humans in Asia, including rat lung worm. Large populations of snails are known to draw rats and mongoose which also represent an additional threat to waterbirds.

The value of kalo to the state and the impacts of the apple snail to taro farming are described in greater detail in the above mentioned *Statewide Strategic Control Plan* (Ibid, 2006). The most frequently used control method is removal of snails and eggs by hand, an intensive and expensive process. Domestic ducks are currently the most effective and efficient method for apple snail control in lo'i kalo (Levin et al. in draft 2006; taro farmer experience).

The koloa (*Anas wyvilliana*) is one of two remaining endemic duck species in Hawai`i[120] and is federally listed as endangered. Several factors contribute to this endangered status; including predation by introduced and feral animals, the loss and degradation of wetlands, lo'i kalo and historic food resources (native flora and fauna species), the presence of established populations of feral Mallards (*Anas platyrhynchos*) (escaped or intentionally released into the wild) that cross-breed with koloa[121]; and overall small numbers of genetically pure koloa. Hybridization with feral mallards and the loss of pure koloa bloodlines through such cross-breeding represents *the* primary threat to recovery of koloa (USFWS 2005). For more indepth discussion on the threat of hybridization to continued survival of koloa in Hawai'i see the *Draft Revised Recovery Plan for Hawaiian Waterbirds* (USFWS 2005) on the web at: http://www.fws.gov/pacific/ecoservices/endangered/recovery/documents/HawaiianWaterbirdsDraftRevRecoveryPlan5-05.pdf

The current statewide population of pure koloa is estimated to be 2,200 birds (USFWS 2005). The largest koloa population is found on Kaua'i (about 2,000 birds). Koloa have been observed in large numbers in USFWS Hanalei National Wildlife Refuge which was, and still is one of the largest wetland taro growing regions in Hawai'i. A small re-introduced population of koloa is located on the island of Hawai'i (about 200). Feral mallard and koloa x mallard populations have now been recorded where only pure koloa were thought to have existed in Kaua'i. Past re-introduction efforts on O'ahu and Maui failed to eradicate existing feral mallard and hybrid populations as a precursor to recovery efforts; those populations are severely hybridized (Engilis et al. 2002). Moloka'i duck populations are also feral and/or hybrid.

Endangered waterbirds and taro farms

Koloa inhabit upland stream habitats, taro patches and wetlands in Hawai'i.[122] Lo'i kalo have provided habitat for waterbirds, including koloa, for centuries, but the loss of forested riparian corridors, wetlands and lo'i kalo over much of the last century has left little suitable habitat for Hawaii's endangered waterbirds. The current degraded conditions of existing wetlands limit the quality of lowland habitat available for koloa. A total of 8,691 acres are recommended as Core and Supporting wetlands for endangered waterbirds, including 209 acres of taro on Kaua'i (USFWS 2005). This represents fully 41% of all taro-growing lands in the state and 89% of the estimated 235 acres in commercial production on Kaua'i. Designating lo'i kalo as waterbird habitat over such a high percentage of crop lands represents an undue hardship to the survival of the taro industry as a whole and farmers individually.

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[120] The second species is the Laysan duck (*Anas laysanensis*) which is not present in the main Hawaiian islands at this time, although reintroductions are being considered.

[121] It is unknown whether migratory Mallards have established permanently in Hawai'i or whether they interbreed with koloa. It has been suggested that because their arrival each year does not coincide with koloa breeding times that this does not occur (VanderWerf and Uyehara, pers. com. 2005).

[122] The degree to which koloa prefer one habitat over another, or whether seasonal changes in habitat preference occur is unknown; however, it is recognized that koloa use both mauka (upland) and wetland habitats (Engelis, VanderWerf , Uyehara, pers. com. 2005)

Viable and active taro lands remaining in the state have declined significantly from 2000 to 2005 (19%) and by more than 600 acres since 1948 (NASS 2000). The costs of bringing a crop to harvest have increased by as much as 50% due to the apple snail (Statewide Strategic Control Plan, 2006). Traditional taro-growing lands under the jurisdiction of state or federal agencies can be limited in the types of control methods allowed in reducing apple snail populations. One such site is the USFWS Hanalei Wildlife Refuge where long-term fallow and the use of domestic ducks are not permitted. Because of such limitations, these taro lands bear the highest density of snails and highest crop losses, statewide. The lack of apple snail population controls in state and federally protected wetlands has also meant that adjacent taro farmers are continually reinfested during flooding events. Mitigation of this situation is sorely needed in a manner that supports both farmers and endangered waterbirds (see discussions on perennial wetlands in the control plan for further discussion on this situation).

Waterbirds and disease

Current Hawai'i state laws prohibit the importation of any domestic ducks due to the risk of such birds carrying West Nile virus or avian flu. Avian flu vectors also include migratory birds that may share habitat with koloa, feral or domestic duck populations. Stable, easily accessible populations of domestic ducks, such as those used by taro farmers for snail control may be able to provide early warning signs of the arrival of such diseases from wild birds through regular testing (J. Burgett, pers. com. 2006).

Tests on nene in Hawai'i have indicated that different strains of malaria may exist on each island (S. Fretz, pers. com. 2005). Feral and domestic waterbirds that move between islands may also exhibit this distinction.

A number of wetlands have had botulism outbreaks in the last decade with a resultant loss of endangered waterbird species. This is due in part to reduced water circulation within ponds. Domestic ducks are also vulnerable to this disease where water sources are not clean. The presence of large masses of decomposing apple snails (snails are often composted after removal from patches) in wet areas may increase opportunities for the formation of the toxin responsible for botulism outbreaks; a danger for both endangered and domestic birds.

Common ground

The USFWS and DOFAW recognize that feral mallard and hybrid duck populations remain the single largest obstacle to restoring and protecting pure koloa in the wild on all islands in the state. State and federal agencies are currently working to establish methods to distinguish between hybrids and pure koloa in the wild and to develop statewide feral mallard and hybrid removal programs.[123] Without an active mallard/hybrid removal program, protection efforts for the koloa are moot.

[123] Those ducks which look most like mallards (dark green head and neck) are easily identified for removal, however, hybrids often look very similar to koloa and only genetic testing is able to distinguish the difference at this time. This has slowed removal efforts.

With the loss and degradation of wetlands in Hawai'i, lo'i kalo have been an important lowland habitat for these birds. There are few enough viable taro lands remaining in the state, and growing kalo is back-breaking work with few financial rewards, even without the added constraints of an endangered species to deal with. While taro farmers support efforts to help the koloa, they also strongly recommend that in conjunction with feral duck control, state and federal agencies focus on restoring currently degraded wetlands outside of traditional taro-growing areas as the primary lowland habitat for koloa and other native waterbirds. Restoration of wetlands will reduce the need to rely on lo'i kalo as waterbird habitat in the long term, without precluding lo'i from contributing to overall available resources for the birds. At the same time, this focus will reduce potential conflicts between the survival of an ancient Hawaiian practice, farmers' livelihoods, and the protection of an equally important endangered species.

Because the domestic ducks used to control apple snails are such a scarce and valuable resource, taro farmers carefully manage their ducks while in the lo'i and pen them nightly, most particularly to protect them from dogs, mongoose and theft.[124] This limits opportunity for koloa-domestic duck interactions on farm and the opportunity for pair-bonding. To date there is no documented or observed face-to-face interactions between domestic ducks used by taro farmers and koloa (Levin, field notes 2004-2006; farmer observation). Both taro farmers and agencies acknowledge that the current source of feral mallards in the islands is not taro farmers' ducks,[125] however, koloa, as with other native freshwater birds in Hawai'i, sometimes choose lo'i kalo as feeding, loafing, breeding or nesting habitat. Although the potential for cross-breeding between koloa and the domestic ducks used by taro farmers for apple snail control remains extremely small due to the way farmers manage their ducks, the possibility may exist.

In response to the drastic levels of apple snail infestation in taro farms across the state, and the economic costs to farmers trying to control this invasive species, agencies agreed that it was important to support solutions for taro farmers wherever possible. Taro farmers agreed it was important to make the use of domestic ducks in apple snail control as responsible as possible to concerns for disease transfer and hybridization.

[124] Best management practices described in this protocol stem primarily from practices currently used by taro farmers.

[125] Taro farmers have been using a limited number of ducks for apple snail control only since 1990 on Maui and after 1995 on Hawai'i; on Kaua'i apple snail control ducks were put into use even later. Suggestions that taro farmers may have lost ducks during hurricanes in the early 1990's are unfounded. Farmers report loss of their ducks from botulism, mongoose, theft and dog attacks. No farmer reported losses due to escape (Levin, field notes 2004-2006). Feral ducks of many breeds have existed in the state for at least a century and a half and numerous populations can be found multiplying on each of the main islands. State and County ponds, wetlands and watercourses are frequent homes of such flocks; ducklings have been available through agricultural stores for decades (this source was terminated with the advent of West Nile and avian flu). Feral mallard population location maps produced by VanderWerf (2004 and 2005) show no overlap between the location of such populations and those of taro farms using domestic ducks on three of four main islands, and only proximity but not overlap on the fourth island (Hawai'i).

Purpose

The purpose of this document is to provide taro farmers with the best recommendations available for using ducks as a method of apple snail control in Hawai'i while protecting to the best degree possible, endemic populations of koloa from further hybridization due to new controlled domestic duck populations in taro farming areas and preventing the establishment of avian diseases.

Duck selection and management practices in each section were derived through discussion of existing taro farmer practices, constraints, and site conditions, along with additional expertise from a variety of sources. Practice criteria included feasibility and accessibility for farmers, simplicity, and level of risk to koloa. In developing these practices, it is recognized that current duckling resources for taro farmers are extremely limited, as are farmer's financial, time and labor resources. Where the best duck variety choices may not be possible, good management practices maintain a high level of prevention.

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I. Duck Characteristics

The following are the best characteristics to look for in domestic ducks used to control apple snails in lo'i kalo. This was determined through the experience of taro farmers who have used a variety of domestic ducks for apple snail control over the last 16 years. The sex, breed, size, behavior, and disposition of the ducks influence the quality of their work in controlling apple snails as well as limit the potential for hybridization with the endemic koloa.

A. Flightless

Domestic ducks that can not fly, or show a reluctance to fly, are best for two reasons: they are easy to control, and the chance that they might join an existing feral population of ducks or koloa is removed.

1. *Naturally flightless*. Some duck breeds are naturally flightless, including the Roen and Indian Runner, but may be a little skittish. Pekin ducks are large-bodied, heavy birds that do not fly and are preferred by taro farmers on the island of Hawai'i.

2. *Pinioned ducks*. A pinioned duck is one that is restrained from flight, either by clipping a wing (must be done after each molt) or removing the wing tip (permanent). Clipping requires regular monitoring. Permanent surgical pinioning is the best option for ducks culled from feral populations.

B. Sex

1. *Females*. Females are less aggressive, and more focused, steady snail eaters than males. Only a limited number of males are needed if fertile eggs are desired, however, during koloa breeding season both male and female domestic ducks should be well-managed.

   a. Past observations (Griffin and Browne 1990 in Engilis et al. 2002) and recent koloa genetics research from a limited sample size suggests that more hybrids may come from a cross between a female mallard and a male koloa (Engilis, Fowler and Eadie, 2005) than previously understood; while earlier documentation also observes male mallards competing with male koloa for the attention of female koloa (DOFAW unpubl. from K. Uyehara, pers. com. 2005).

   b. Pairing in koloa can occur year-round; however, late fall and early winter are the primary seasons. Some domestic ducks currently used by taro farmers appear to not engage in sexual activity, and even egg-laying, during this same period (Pekin, Cayuga, Ruen, and Indian runner; observations from Maui)

2. *Sterile ducks*. An option that resolves the reproductive and flight issues of using domestic ducks near koloa populations is sterile ducks. No sterile ducks are available in Hawai'i and it is difficult to produce them. Mule ducks (mullards) are available from at least one source in California (Metzer Farms) but would need to be brought in under a special HDOA research permit. Research needs to be conducted with taro farmers to determine whether sterile ducks will be a good snailers or do damage to plants and banks. This may be a viable option for sites such as Hanalei.

a. A mule or Mullard is a cross between a Pekin female and a Muscovy male; a hinnie is the result of a Pekin male and Muscovy female. A mule is typically large, swims well but does not fly. Hinnie females fly. Approximately 60% of mules are male. Both mules and hinnies are sterile. A female hinnie can lay eggs but they do not hatch. It is however, difficult to breed Pekin and Muscovy and the resulting eggs have only a 20-30% fertility rate.[126] These birds are raised on the mainland primarily for pate (liver). They have characteristically large, clawed feet like a Muscovy (potential to damage banks) and are untested for their behavior in taro lo'i (pers. com. John Metzer 2005).

b. A veterinarian can sex and sterilize ducklings, however, to our knowledge there is currently no one in the state of Hawai'i with this experience. Costs are unknown.

C. Trainable

1. *Start with ducklings*. Young ducks will readily become familiar with a farmer, a routine, and the snails as a food source, as a form of imprinting/training. Adult birds will take a few days to introduce into an existing flock but will adapt quickly to a trained flock. Adults may have difficulty bonding with a farm and new routine where there are no existing birds to learn from.

   a. Ducklings require more intense inputs and care during the first three months (see below); they may not always be available.

   b. If adults ducks are all you have access to, start with a few birds, keep them close to their new home by housing and feeding them in a pen near the lo'i and develop a familiar routine with them before you expand your flock.

2. *Well-mannered*. Choose breeds that are mellow in nature, quiet (Mallards are noisy), easy to herd, quick to get into the routine of snail feeding, and can be left to themselves once in the taro patch. Duck breeds that are easily spooked will require more attention and time to watch. Herd dogs have been suggested as an option which could also provide some protection from hunting dogs, however, that involves an additional commitment of time, training and feed/care costs. No taro farmers have attempted to use herd dogs.

D. Able Feeders

1. *Age*. Juvenile ducks will eat more snails than mature ducks. If your ducks survive dogs, mongoose and disease, they will live an average of 5-6 years and will need to be replaced. Introduce new ducklings into your existing flock rather than starting a new juvenile group; the adult birds will influence the behavior of the young ones.

2. *Breed*. Not all domestic ducks feed alike. Small beaked birds will be limited to consuming smaller-sized snails. Based on current farmer experience, Pekin and Black Cayuga appear to be the most capable snail feeders.

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[126] Results increase to 80% with artificial insemination. Hatching takes 32 days versus 28 days for Pekin and 35 days for Muscovy (J. Metzer, pers. com. 2005 and at www.metzerfarm.com).

E. Breed

Most domestic ducks (*Anas platyrhynchos f. domestica*) derive from Mallard (*Anas platyrhynchos*) bloodlines with the exception of Muscovy; some have more direct bloodlines than others. For the protection of koloa, it is important to recognize that any domestic duck has the potential, however remote, to breed with a koloa, but only if that opportunity is allowed to occur through poor management.

1. *Most recommended*. Pekin appears to be the best breed due to its larger size (koloa are small birds), visibility (they are all white), lack of desire or ability to fly, large appetite for snails and quiet, easy nature.[127] Black Cayuga's are also excellent snailers and easy to work with.

   a. Pekin are most easily distinguished from all other duck breeds because of their all white coloring and size. They average 5 - 7 pounds compared to Mallards (2 - 4lbs) and koloa (under 1.5lbs).

2. *Other breeds*. Flightless Roen, Cayuga, Khaki Campbell, and Blue Swedish, among other breeds have been used to varying degrees of success by taro farmers; however, Pekin and Black Cayuyga remain the most efficient snailers, partially due to their larger size. Some of these breeds look somewhat similar to Mallards; each has distinguishing factors.

3. *Not recommended*. Three breeds are not recommended based on their characteristics and relationship to feral duck populations. Taro farmers should observe other duck breeds carefully to determine if there are other varieties that may belong in this category in the future.[128]

   a. Flightless Indian Runners, noted for their upright stance, have been used with some success by taro farmers, but this breed can be somewhat nervous and timid. They also have some tendency to tear at the banks and are not recommended as a breed for apple snail control due to these habits.

   b. Mallards are not recommended for use in apple snail control because they are strong flyers. Their presence in existing feral duck populations and prominent role in koloa hybridization makes them a high risk for apple snail control flocks.

   c Muscovy (*Cairina moschata*) are not Mallards but are harder to control. They have long talons which tear up the banks of the lo'i and tend to dig around the base of

[127] The Pekin was introduced to American in the 1870's from China. The likelihood of a Pekin duck crossbreeding with koloa is extremely small; there are no occurrences documented in Hawai`i since the breed's arrival more than 120 years ago. However, because they also originally derive from Mallard bloodlines that slim chance remains.

[128] The idea of using koloa for apple snail control in protected areas was explored during discussions at the January 2005 duck roundtable, however, their small size and small beaks limit their ability to be effective, especially in heavily infested sites. Their protected status also brings up additional issues that neither agencies nor taro farmers are prepared to deal with at this time.

the kalo more than other breeds. They also fly. The Muscovy is traditionally more of a land duck than a water duck.

4. *Working with what you have*. Pekin ducklings and adults, as well as ducklings and adult birds of most breeds are scarce in the present market on all islands. If all you have access to are lesser preferred breeds, use what you have and implement the practices described in this document to keep your ducks safe and prevent koloa interactions. If the only birds available to you are mallards; forgo their use and wait for other birds.

II. Penning and caging

Penning and caging serve several purposes, including to protect your ducks from dogs and mongoose, to reduce opportunities for koloa interactions, to control breeding within your own stock, and to keep capture and herding simple.

A. '<u>Home-base' Pens or Cages</u>

1. *Weeks one through four*. Ducklings require <u>frequent</u> attention during the first three to four weeks and should be kept in a sheltered, warm, small cage or box away from dogs, mongoose, rain, wind, and dirty water to improve survival rates. Duckling feed during this time is typically "chick starter".

2. *Juveniles and Adult Pens*. There are many options. The simplest, least costly designs are described below.

   a. Brood shelter with protective fence. A cage of wire and plywood (approx 4x6 ft) about three feet off the ground on 2x4 inch legs with a plywood roof and strong wire flooring makes a good brooding and shelter house. This keeps them dry and out of the rain. This sized pen holds up to 10 ducks if they are let out to forage often.

   A dog proof fence of heavy wire around this structure is strongly recommended. Both can be light weight enough to move around. Ducks will walk down a ramp into a cage or trailer to be moved. A true mongoose-proof fence is extremely expensive; setting out traps may be more cost effective and reduces overall numbers of this pest for your ducks and koloa.

b. Over an 'auwai or lo'i edge. A wire and plywood cage built on the ground, half over the 'auwai and half on solid ground works well for farmers who are not able to be on-farm daily. The ducks will always have clean water and some food from the 'auwai. Solid lower walls will protect the ducks from dogs and also keep them calm when penned. Very strong wire needs to be used to dog-proof the cage. Place cobbles along the `auwai edge to protect the banks from eroding. Maximum 6 ducks.

c. For more than 6 ducks. A four to six foot high chain link pen about 15ft in diameter with water piped into a small pond in the center and piped out to a lo'i (natural fertilizer) is a more natural environment for ducks that are not worked daily. A cage fits inside for ducks that need shelter or to grow out ducklings. Mongoose-proof the lower edge if you plan to collect eggs. From 15 to 20 ducks can be managed in this type of pen.

B. <u>In the lo'i</u>

1. *Lo'i perimeter*. Flexible plastic fencing may help keep your ducks in the proper lo'i as they begin to learn the system of feeding and returning to their pen. Once the pattern is established such fencing is not usually necessary. This type of fencing does not protect ducks from dogs.

2. *Farm perimeter*. Stray dogs are the number one source of duck loss for taro farmers. They can indiscriminately kill a whole flock in very short time. You may need to hogwire the perimeter of your farm to keep stray dogs out.

These options are expensive and an additional aggravation for farmers. Fencing lo'i or farm perimeters does not fit the spirit or traditional practice of farming kalo where each lo'i cluster is connected to the next farm by water, berms and pathways. However, if dogs remain an unresolved problem in your area, you may want to implement this practice on your farm, or jointly with your neighbors.

III. Working the ducks

A. <u>Duck numbers</u>

1. *Initial flock size*. In an infested lo`i, 12 ducks working daily for 3-4 weeks will bring snails under control. In heavily infested taro patches, such as those in Hanalei, higher

numbers of ducks may be needed initially to suppress populations to more manageable levels.

2. *Maintenance*. Three to 6 ducks can maintain a patch once the snail population drops to a lower level. Coordinate duck movement among lo`i in relation to snail cycles and seasonal population blooms (see the Strategic Control Plan for Apple Snails, 2006, for descriptions of the snail's ecology and behavior).

3. *Replacement stock*. It is important to have a few ducklings or juveniles on hand to replace any adults that may be lost to age, dogs, mongoose, theft or disease.

B. <u>Patterns</u>

3. Work from the beginning of your water source towards the most makai portion of your lo`i. Pick large snails and eggs as ducks clean up medium and small snails. For more control over which lo`i the ducks will feed in first, use a 2ft high moveable fence to isolate the patches you want cleaned and contain the ducks.

4. Prior to planting, a series of dry-downs and flooding will effectively bring snails to the surface. Remove the largest ones by hand and let the ducks go after the smaller ones. They will fertilize the patch in the process.

C. <u>Timing</u>

1. Ducks will feed, rest, play, and return to feeding in cycles during the day. You will observe this activity if you leave your ducks in the lo'i all day long. They may occasionally lose interest in feeding on snails and damage the taro plants, particularly when snail numbers are low. A better alternative is to release ducks to feed on snails a few hours at a time, once or twice per day, and return to the home pen to keep them focused on the snails. This also reduces opportunities to wander.

    a. There are times when you don't want ducks in your lo'i. After initial planting, when huli are young, ducks will knock down and nibble on huli. When apple snail populations are low, and/or when pocket rot is prevalent, ducks will dig into the taro plants in search of food and undermine them. Too many ducks in one patch will result in the same type of behavior.

    b. While there is no evidence of harm, you may not want to have ducks in your lo'i immediately after fertilizing a patch in order to protect the health of your ducks.

    c. Taro farmers from several sites have observed koloa are most active at dusk and in the evenings. Keep your ducks penned up at during these times. This will close the door to potential interactions, and equally important, protect your ducks from roaming dogs.

D. <u>Guidance</u>

1. *Teaching*. Your ducks will follow your lead as you go to and from the lo'i. Use a cup of grain to encourage them initially. Walk them out to the fields you wish them to

feed in to get them started each day. Eventually they will know which fields have the most snails and work them on their own. They particularly like to follow in the lo'i after weeding and leaf or corm harvest when snails, insects and other fauna have been disturbed.

2. The best case scenario is to remain in the area working. Let the ducks out. They will fill up on snails quickly if they are hungry. Then they clean themselves, rest, eat other bugs and grass and will go after the snails again. Train them to go back to their cage at your own signal (ie. whistling, clapping, calling, shaking a grain can).

3. If you can not be at your lo'i for long, let the ducks out for one-half to one hour where there are plenty of snails. Pen them after they have eaten and come back later in the day to let them out again for another cycle.

IV. Other

1. *Crowding*. Too many ducks penned up for too long is stressful and the weak ones will suffer. Crowding can also increase opportunities for diseases to occur. Be sure to allow ducks time to forage and exercise in the lo'i with enough frequency to keep ducks alert and healthy.

2. *Identifying farm ducks*. Fitting domestic ducks with brightly colored, easily recognizable farmer-specific plastic bands adds an additional measure of security and assurance. Banded ducks will also be more easily identifiable and trackable for agencies responsible to monitor diseases (ie. an additional band can be placed on those ducks that may be swabbed for avian flu regularly). Bands may help farmers more easily identify their birds in relation to dog attacks or theft. They also provide further opportunity for researchers and farmers to clarify whether interactions between taro field ducks and koloa actually occur or not.

   Plastic bird bands are available on the web at www.avinet.com in varying sizes and colors for approximately $4 per 10 bands (as of 5/2006).

V. Disease prevention

There are a number of diseases that may affect domestic ducks used by taro farmers in apple snail control. Taro farmer isolation from most existing feral duck populations adds a degree of protection for disease transmittal but is not a guarantee that disease will not occur. Two newer diseases, West Nile virus and avian flu are virulent and a high risk for transmittal to humans. Neither is found in Hawai'i as of September 2006.

General guidelines for disease prevention and control of all types should include the following:

1. *Cleanliness*. Keep pens and water sources clean and flowing. Keep supplemental feed fresh, dry, and sealed from rats and other vermin to limit opportunity for bacterial growth and molds. Be observant of your flock's health and vigor. Listless behavior, weight loss, and dull plumage may be indicators of poor nutrition or the onset of disease. Sick birds will typically stop feeding and may be feverish to touch.

2. *Isolation*. Any duck that shows signs of illness should be isolated from the flock immediately; do not transport to or allow to mix with other duck or waterbird populations. Keep a sick duck away from ducklings or juveniles especially.

3. *Contact the appropriate state or federal wildlife agency to report the outbreak* of disease. As of this writing (Sept 2006), USFWS is the lead agency for testing of avian flu. The Department of Health is responsible for tracking West Nile virus. The Department of Agriculture is the place to report disease among flocks of chickens, ducks and other poultry.

   a. Ducks (or other birds) freshly dead (less than 48 hrs) and intact (not scavenged) should be carefully bagged and kept cool (if delivered the same day) or frozen (if delivery is delayed). At this time, birds must be delivered to the appropriate facility; there is no pick up for West Nile virus. This is not practical for taro farmers in most locations; however, a full description of how to collect and report dead birds is available on the web at: http://www.hawaii.gov/health/family-child-health/contagious-disease/wnv/surveillance/collection

   b. The USFWS has proposed weekly swabbing of "sentinel duck populations" (domestic ducks that remain in a place over time and are a frontline sentry for the entry of avian flu to Hawai`i) to monitor avian flu. Rather than establish new populations of these ducks, they have requested the participation of taro farmers who use ducks for apple snail control. USFWS staff would be responsible for all testing, data recording and monitoring for disease in this case.

3. *Transport*. It is unknown at this time whether domestic ducks in Hawai'i are carriers of avian malaria. DLNR-Division of Forestry and Wildlife can provide testing for avian malaria for projects that may need to move ducks from one island to the next.

Other diseases known to affect domestic ducks:

1. *Avian botulism*. Domestic ducks are susceptible to botulism in the same way that wild waterbird populations are in Hawai'i. Contaminated water sources are a vector for this disease and can cause the loss of an entire flock within a few days. Providing a clean, dry shelter and clean drinking and bathing water sources will reduce the likelihood of an avian botulism outbreak. Keep your ducks from drinking or playing in stagnant, polluted water sources (ie. effluent ponds or water where any dead animal/fish has been observed). Clean their bowls regularly.

   The build-up of apple snail populations in shallow, slow-flowing water has not yet been documented to be a vector for botulism outbreaks but the threat exists;

particularly if a large dieback occurs. Dispose of snails removed during hand-picking activities in areas that can not drain or be washed back into lo'i, 'auwai, streams or ponds (or where rains can not wash through a pile or pit and carry pathogens into freshwater sources). Add vegetation and lime to increase the speed of decomposition.

The dead carcasses of any animal (ie. mongoose, rats, etc) should be disposed of away from water to reduce botulism vectors.

2. *Alpha-toxin poisoning*. Older feeds and feed exposed to dampness, particularly fishmeal or peanut-based feeds, may attract fungal growth that can be the source of toxins that cause rapid mortality in a flock, especially ducklings. Buy only fresh feed and store in airtight containers in a well ventilated, covered area.

Pekin ducks appear to be the best duck breed for apple snail control. Currently, this breed is not available to most farmers and, without the assistance of federal and state agencies it may take some time before that changes. In the interim, the practices described above will improve the effectiveness of apple snail control measures and increase safety levels for koloa populations, simultaneously. Ultimately, the reduction of apple snail populations in lo'i kalo and protected wetlands will improve economic conditions for taro growers and the quality of available habitat for endangered waterbirds.

Appendix B:

Exerpt by permission (pgs 145-162):

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5 Apple Snails (Ampullariidae) as Agricultural Pests: their Biology, Impacts and Management

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What are Apple Snails?

Ampullariidae are freshwater gastropod snails predominantly distributed in humid tropical and subtropical habitats in Africa, South and Central America and South-East Asia. They include the largest of all freshwater gastropods (*Pomacea urceus* (Müller) can attain a shell height of 145 mm (Burky, 1974); *Pomacea maculata* Perry can exceed 155 mm (Pain, 1960)) and frequently constitute a major portion of the native freshwater mollusc faunas of these regions. Among the seven to ten genera usually recognized, the two largest are *Pomacea* Perry, with about 50 species, and *Pila* Röding, with about 30 (Berthold, 1991). Species of these two genera, in particular, are frequently known as 'apple snails', because many bear large, round, often greenish shells. They have also become known as 'mystery snails', 'miracle snails', 'golden snails', 'golden apple snails' and by various local names (for instance, 'kuhol' in the Philippines, 'bisocol' in the Filipino community in Hawaii).

There are a few instances of ampullariids causing damage to crops, predominantly paddy rice (*Oryza sativa* Linnaeus; Gramineae), in their native ranges. More significantly, a number of species have been introduced outside their native ranges in recent years and have become serious agricultural pests. In this review I summarize relevant aspects of ampullariid biology, focusing on the pest species; I then outline the agricultural problems they are causing and the control measures that have, generally unsuccessfully, been implemented; and finally I make suggestions for future approaches and needs in order to address the problems.

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Classification, Diversity and Natural Range

Ampullariidae (= Pilidae of some authors (Cowie, 1997a; ICZN, 1999)) are operculate gastropods. They are most closely related to the Viviparidae, together with which they form the superfamily Ampullarioidea in the orders or superorders (depending on classification) Mesogastropoda of earlier authors and Caenogastropoda of more recent authors (Ponder and Warén, 1988; Berthold, 1989; Bieler, 1992).

Traditional subdivision of the family has been reliant on characters of the shell, siphon and operculum as taxonomically diagnostic (e.g. Michelson, 1961). Pain (1972) briefly reviewed the history of taxonomic work on the family. More recently, Berthold (1991, pp. 245–250) recognized ten genera with approximately 120 species. His detailed anatomical account treated representative species from each of these generic groupings. He divided the family into two subfamilies: the Afropominae (containing a single Recent African species in the genus *Afropomus* Pilsbry & Bequaert); and the Ampullariinae, which he subdivided into the tribes Sauleini (one genus, *Saulea* Gray, containing two African species, one Recent, one fossil) and Ampullariini (the remainder). He further subdivided the Ampullariini into the groups Heterostropha and Antlipneumata, but these divisions and names have been criticized by Bieler (1993), who reanalysed Berthold's data using cladistic techniques. In Bieler's reanalysis the various groupings of genera remained more or less similar to those of Berthold, but the relationships among groups were inconsistent. Given these inconsistencies, the suprageneric taxonomy of ampullariids remains unstable. One of the ten genera recognized by Berthold (1991), *Pseudoceratodes* Wenz (African, fossil only), was included in the family only tentatively. Of the remaining nine genera, six contain fewer than four species each: *Afropomus* and *Saulea* are African; *Asolene* d'Orbigny, *Felipponea* Dall, *Pomella* Gray and *Marisa* Gray are South American. The three genera *Lanistes* de Montfort, *Pila* (*Ampullaria* de Lamarck and *Ampullarius* de Montfort are junior synonyms (Cowie, 1997a; ICZN, 1999)) and *Pomacea*, containing 21, about 30 and about 50 species, respectively, comprise the great majority of species in the family. *Lanistes* is African (including Madagascar). *Pila* is African and Asian. *Pomacea* is South and Central American.

Berthold (1991) hypothesized a Gondwanan origin for the family, specifically in that part of Gondwana that was to become Africa. The group is assumed to have spread and diversified on to the South American and Indian plates, but failed to reach the Australian plate prior to the breakup of the supercontinent. An alternative scenario, less favoured by Berthold (1991), involved postulated extinctions on the Antarctic/Australian plate. As the plates moved to their present positions, the group probably spread and diversified within the humid tropics and subtropics (in particular from the Indian plate into South-East Asia) to their physiological/ecological limits, defined approximately by the

10°C minimum annual temperature isotherm and the 600 mm annual precipitation isohyet (see also Baker, 1998). The limit of their distribution in South-East Asia (genus *Pila*) corresponds closely with Wallace's line, despite New Guinea and parts of Australia apparently being suitable climatically. Wallace's line corresponds essentially to the boundary between the Asian and Australasian plates; ampullariids simply have not yet reached Australasia.

The genus *Pomacea*, which is the main focus of this review as it contains the majority of the pest species, is found throughout most of South and Central America and the Caribbean, with a single species, *Pomacea paludosa* (Say), extending into the south-east of the USA. The genus is divided into two subgenera, *Pomacea sensu stricto* and *Pomacea* (*Effusa*) Jousseaume. But the relationships among these two subgenera and the genus *Marisa* are not well resolved (Bieler, 1993) and, at least in terms of shell morphology, the three taxa intergrade (R.H. Cowie, personal observations).

Biology

A thorough understanding of relevant aspects of the biology of pest species is important if effective management strategies are to be developed. With knowledge of the animals' ecology, behaviour and certain aspects of their physiology, it may be possible to manipulate their environment to reduce reproductive output, to provoke behaviour that facilitates mechanical control, to apply pesticides at appropriate points in the life cycle and so on.

Unfortunately, detailed knowledge of the biology of ampullariids is sparse and scattered. *Pomacea* is the best-known genus, and various species have been the subject of basic studies of systematics, anatomy, physiology, genetics, distribution, behaviour and so on. *Pila* has been investigated to a lesser extent. *Marisa* has attracted interest, often because of the perceived value of *Marisa cornuarietis* (Linnaeus) in controlling other gastropod species that are vectors of schistosomes (e.g. Demian and Lutfy, 1966; Robins, 1971; Demian and Yousif, 1975; Peebles *et al.*, 1972; Pointier *et al.*, 1988, 1991). The basic biology of the other genera is hardly known (Berthold, 1988).

There have not been studies directly focusing in detail on aspects of the biology of the pest species that might be most relevant to the development of control measures. In the sections that follow, I have attempted to summarize what is known in these areas, mostly regarding species of *Pomacea*. I have not attempted to review areas of less relevance, such as embryology (e.g. Demian and Yousif, 1973, 1975), anatomy and histology (e.g. Andrews, 1964, 1965a,b; Keawjam, 1987), karyology (von Brand *et al.*, 1990), genetics (Fujio and von Brand, 1990; Keawjam, 1990), biochemistry and physiology (Little, 1981).

Habitat

Ampullariids are freshwater inhabitants. Some may be able to tolerate low levels of salinity (Prashad, 1925b; Hunt, 1961; Santos *et al.*, 1987; Fujio *et al.*, 1991a), but they generally do not live in brackish-water habitats. Most species are amphibious, able to spend significant lengths of time out of water breathing air. Many species, especially species of *Pomacea*, *Marisa*, *Pila* and *Lanistes*, inhabit slow-moving or stagnant water in lowland swamps, marshes, ditches, lakes and rivers (e.g. Pain, 1950a, 1960; Andrews, 1965b; Robins, 1971; Louda and McKaye, 1982; Keawjam, 1986). Some species could be considered preadapted for living in rice paddies, taro (*Colocasia esculenta* (Linnaeus) Schott; Araceae) patches and other similar artificial habitats in which aquatic crops are grown. There may be differences in habitat among closely related species. For instance, in Argentina, Scott (1957) reported that *Pomacea canaliculata* (de Lamarck) inhabited relatively still water, while the almost indistinguishable *Pomacea insularum* (d'Orbigny) was found in rivers. In Lake Malawi, five species of *Lanistes* occupy marshy areas and the lake edges, with the lake-edge species being generally found at slightly different depths (Louda and McKaye, 1982). In Thailand, the five native species of *Pila* have overlapping distributions but slight differences in habitat preferences (Keawjam, 1986). The Asian genus *Turbinicola* Annandale & Prashad (treated as a synonym of *Pila* by Berthold (1991)) is found in fast-flowing hill streams, and exhibits a somewhat more terrestrial existence than other ampullariids (Prashad, 1925a; Andrews, 1965b; Keawjam, 1986; Berthold, 1991). *Limnopomus* Dall, a subgroup of *Pomacea* treated as a distinct genus or subgenus by some authors but synonymized by Berthold (1991), also inhabits swiftly flowing mountain streams (e.g. Pain, 1950a,b, 1960).

Reproduction, growth and demographics

Breeding system

Ampullariids are dioecious, internally fertilizing and oviparous (not reciprocally fertilizing hermaphrodites as stated by Chang (1985)). There is evidence that females are larger than males, at least in some species (Prashad, 1925b; Robins, 1971; Keawjam, 1987; Marwoto, 1988; Lum-Kong and Kenny, 1989; Cazzaniga, 1990a; Perera and Walls, 1996; Wada, 1997; Estebenet and Cazzaniga, 1998). The extent of dimorphism may vary among populations within species: it may be slight (Cazzaniga, 1990a) or dramatic (Fig. 5.1); and it is possible that this has caused considerable nomenclatural and taxonomic confusion. Preliminary study of *P. canaliculata* in Hawaii found no size dimorphism and an approximately 1 : 1 sex ratio in the wild, although in the laboratory females grew faster than males under certain feeding regimes (H. Ako and T. Nishimura, Honolulu,

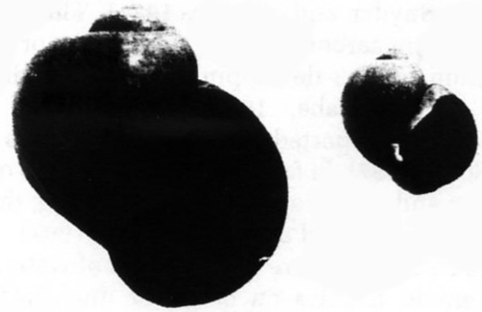

Fig. 5.1. A mating pair of *Pomacea canaliculata* (de Lamarck) (Ampulariidae), collected by the author from a domestic rearing facility in Phnom Penh, Cambodia, in November 1995; female on the left, shell height 84 mm.

personal communication, 1997). In addition to size dimorphism there appears to be some slight dimorphism in shape of the aperture and operculum. In *P. canaliculata*, females have a broader shell aperture (Cazzaniga, 1990a) and a concave operculum (convex in males) (Adalla and Morallo-Rejesus, 1989; Anon., 1989; Guerrero, 1991; Schnorbach, 1995) (H. Ako (personal communication, 1997), says it is the other way round: females have convex opercula). In *M. cornuarietis*, the shell aperture of males is said to be more round compared to the more oval shape in females, and males are said to produce thicker, more heavily ridged shells (Robins, 1971). Species of *Pila*, and perhaps *Pomacea*, have been reported to change sex (Keawjam, 1987; Keawjam and Upatham, 1990). The sex change is from male to female (protandry) and takes place during aestivation (*Pila*) or without aestivation (*Pomacea*). The larger size of females in *Pila* has therefore been attributed to age, with continued growth following protandric sex change (Keawjam, 1987). The ubiquity and significance of this phenomenon need further investigation; it was not reported by Andrews (1964) in her detailed account of the functional anatomy and development of the reproductive system in *P. canaliculata* or by Estebenet and Cazzaniga (1998) in their study of dimorphism in the same species.

Mating, oviposition, eggs and fecundity

Breeding in many species is seasonal and apparently related to latitude, temperature and rainfall (Andrews, 1964). In equatorial regions, many species aestivate during the dry season as their habitats dry up (see below), breeding in the rainy season; in subtropical regions, ampullariids may only breed during summer, once temperatures reach a certain level (Scott, 1957; Andrews, 1964). Local variation in reproductive regime may be related to local climatic variation, especially availability of water (Bourne and Berlin, 1982).

Species of *Pomacea* generally lay their eggs above water on exposed substrates, such as vegetation and rocks, perhaps to avoid aquatic predators or in response to low oxygen tension in their often near-stagnant aquatic habitats (Snyder and Snyder, 1971). The eggs are individually enclosed in a calcium carbonate shell, which may or may not be used as a source of calcium for the developing embryo (Andrews, 1964; Tompa, 1980; Turner and McCabe, 1990). The eggs of *Pomacea scalaris* (d'Orbigny) have been reported to lack the calcareous shell and to be laid under water (Scott, 1957). In fact, as for other species of *Pomacea*, they are laid out of water and do have a calcareous coating; they are salmon-pink (A. Castro-Vazquez, personal communication, 1997).

The eggs of *Pila* species are also laid out of water, but in depressions made by the gravid females on banks or mud-flats (Michelson, 1961; Andrews, 1964; Keawjam, 1986). They have a calcareous coating (Prashad, 1925b; Keawjam, 1986). In India, *Pila* begin laying their eggs at the start of the rainy season (Prashad, 1925b; Andrews, 1964). The eggs of *Turbinicola* have a calcareous coating and are laid out of water attached to stones (Prashad, 1925a). Those of *Marisa*, *Lanistes* and *Asolene* lack the calcareous coating (Keawjam, 1986) and are deposited under water on submerged vegetation or other surfaces (Michelson, 1961; Robins, 1971; Albrecht *et al.*, 1996).

In *P. canaliculata*, and indeed other *Pomacea* species (e.g. *Pomacea dolioides* (Reeve) (van Dinther, 1956); *Pomacea haustrum* (Reeve) (Guimarães, 1981a,b); *Pomacea paludosa* (Perry, 1974)), oviposition (above water) takes place predominantly at night or in the early morning or evening (Andrews, 1964; Chang, 1985; Halwart, 1994a; Schnorbach, 1995; Albrecht *et al.*, 1996), about 24 h after copulation (up to 2 weeks after mating, according to Chang (1985)). Andrews (1964) and Albrecht *et al.* (1996) described copulation in *P. canaliculata* in detail; it occurs at any time of the day or night (Naylor, 1996; R.H. Cowie, personal observations), although there may be some diurnal rhythm, and it takes 10–18 h. Individuals mate repeatedly, about three times per week (Albrecht *et al.*, 1996). On each oviposition occasion, a single clutch is laid, of highly variable egg number (Table 5.1). The interval between successive ovipositions has been reported as 12–14 days (Chang, 1985) and about 5 days (Albrecht *et al.*, 1996) for *P. canaliculata* and 8–16 days for an unidentified '*Ampularius* sp.', presumably *P. canaliculata* (Lacanilao, 1990). Hatching generally takes place about 2 weeks after oviposition, but this period varies greatly (Table 5.1). Newly hatched *Pomacea* immediately fall or crawl into the water. On average, one animal can produce 4375 (maximum observed 8680) eggs per year (Mochida, 1988a, 1991), which, if clutch size is about 200 (Table 5.1), translates into about 22 clutches (see also Anon. (1989), which gave an even higher figure of up to 1200 eggs per month). Development is highly dependent on temperature (e.g. Robins, 1971; Demian and Yousif, 1973; Aldridge, 1983; Mochida, 1988a,b; Estebenet and Cazzaniga, 1992; Schnorbach, 1995), and therefore locality, which probably largely accounts for the variability in the data for *P. canaliculata* in Table 5.1. The eggs of *M. cornuarietis* take 8 days to hatch at 25–30°C and 20 days at 15–20°C; those of *Pila globosa* (Swainson) take 10–14 days at 32–38°C and 3 weeks at 21–27°C (Demian and Yousif, 1973).

Table 5.1. Reproduction and growth in Ampullariidae. Asterisks indicate laboratory studies. Some data have been reported without indicating whether they were obtained from laboratory cultures or from the wild. Some of the references listed undoubtedly simply reiterate data from others that are also listed. Some, at least, of the variability exhibited (especially by *Pomacea canaliculata*) may be due to taxonomic confusion (see text).

Species	Locality	Clutch size	Hatchability (%)	Time to hatching	Time from hatching to maturity	Longevity	References
Pomacea canaliculata (de Lamarck)							
	Argentina	120–478					Cazzaniga and Estebenet (1988)
	Argentina			28 days			Scott cited by Demian and Yousif (1973)
	Argentina*			12–15 days			Thiengo *et al.* (1993)
	Argentina*				7 months–2 years	13 months–4 years	Estebenet and Cazzaniga (1992)
	Argentina	Mean 101	43				Albrecht *et al.* (1996)
	Argentina*				100–150 days		Estebenet and Cazzaniga (1998)
	Philippines	25–320		10–15 days	60 days	2–3 years	Adalla and Morallo-Rejesus (1989)
	Philippines	25–500		7–14 days	59–84 days	119 days– > 3 years	Anon. (1989); Olivares *et al.* (1992)
	Philippines	25–500		10–15 days	60–85 days	2–3 years	Halwart (1994a)
	Philippines*	50–400	20.9–35.0	9–12 days			Lacanilao (1990) (as '*Ampularius* sp.')
	Philippines	50–500		10–15 days	< 1 year		Guerrero (1991)
	Philippines	25–500	80	8–15 days			Rondon and Callo (1991)
	Philippines		80				Bombeo-Tuburan *et al.* (1995)
	Philippines	25–320	90–100	8–21 days		3 years	Schnorbach (1995)
	Taiwan*	200–300	60	Average 12.4 days	55 days		Chang (1985)
	Japan*	Average 200–700	41.9	12 days	6 months		Fujio and von Brand (1990); Fujio *et al.* (1991a,b)
	Japan	30–700	7–90		2 months	> 2 years	Wada (1997)
	Thailand	800–1000					Keawjam and Upatham (1990)

Table 5.1. (*Cont'd*)

Species	Locality	Clutch size	Hatchability (%)	Time to hatching	Time from hatching to maturity	Longevity	References
	Asia	321 (average)	7–90	9–37 days	2–3 months	2–5 years	Halwart (1994a); Mochida (1988a,b, 1991)
	Asia	320	7–90		60–90 days		Naylor (1996)
	Asia	25–500	7–90	8–15 days	60–90 days	4 years	Heidenreich and Halwart (1995); Heidenreich *et al.* (1997)
	Hawaii	200–500		7–14 days	3–4 months	2–5 years	Glover and Campbell (1994)
	Hawaii	*c.* 200		3 weeks	3–4 months	3–4 years	Kobayashi *et al.* (1993)
	Hawaii	350		2–3 weeks			Tamaru and Hun (1996)
	Hawaii				10 months		Laeh *et al.* (2001)
	England*	100 +			< 12 months		Andrews (1964)
Pomacea dolioides (Reeve)							
	Surinam	200–300 (max. 437)		13–16 days	8–12 months	c. 18 months?	van Dinther (1956, 1962) (as '*P. lineata*')
Pomacea gigas (Spix)							
	Not known			2–6 weeks			Köhler cited by Demian and Yousif (1973)
Pomacea glauca (Linnaeus)							
	Surinam	30–90		14–17 days	8–12 months	*c.* 18 months?	van Dinther (1956, 1962)
	Guadeloupe				13.5 months	*c.* 3 years	Pointier *et al.* (1988)
Pomacea haustrum (Reeve)							
	Brazil*			15–23 days	374–529 days		Guimarães (1981a)
	Brazil	236		9–30 days			Guimarães (1981b)
	Brazil				< 1 year		Estebenet and Cazzaniga (1992)

Table 5.1. (*Cont'd*)

Species	Locality	Clutch size	Hatchability (%)	Time to hatching	Time from hatching to maturity	Longevity	References
Pomacea lineata (Spix)							
	Brazil*	Average 100		15 days			Thiengo (1987)
Pomacea paludosa (Say)							
	Florida, USA	Mean 26.7 (max. 141)		18–28 days			Hanning (1978)
	Florida, USA	3–50, 80		15–20 days			Perry (1974)
Pomacea urceus (Müller)							
	Trinidad	21–93	0–84*	22–30 days*			Lum-Kong and Kenny (1989); Lum-Kong (1989)
	Venezuela	50–200			6–7 months	2.5–3.5 years	Burky (1973, 1974)
Marisa cornuarietis (Linnaeus)							
	Egypt*			8–20 days			Demian and Yousif (1973)
	Florida	Max. 210		11–24 days			Robins (1971)
Pila globosa (Swainson)							
	India	200–300		*c.* 1 month			Prashad (1925b); Andrews (1964)
	India			10 days – 3 weeks			Ranjah cited by Demian and Yousif (1973)
Pila polita (Deshayes)							
	Not known			< 14 days			Semper cited by Demian and Yousif (1973)
Pila spp.							
	Thailand					At least 3 years	Keawjam (1987)
Lanistes nyassanus Dohrn							
	Lake Malawi					5–10 years	Louda and McKaye (1982)

A very different strategy is adopted by *Pomacea urceus* (Burky, 1973, 1974; Lum-Kong and Kenny, 1989). This species mates towards the end of the rainy season. Females then bury themselves into the muddy substrate and aestivate as their marshy habitat dries out. *P. urceus* living in permanent rivers also aestivate, burying themselves into the river banks above the water level. Eggs are laid at the start of the aestivation period and are maintained within the shell, between the operculum and the aperture. Development takes place during the dry season, within the female's shell (even if she dies). The young hatch but remain and aestivate within the female's shell until the start of the rainy season. Burky *et al.* (1972) argued that this strategy protects the newly hatched juveniles from high (possibly lethal) temperatures and water loss during the dry season. *P. urceus* is the only ampullariid known to adopt this strategy.

The eggs of most species of *Pomacea* are brightly coloured, perhaps as a warning of unpalatability since the eggs appear to be distasteful, at least to vertebrates although perhaps not to invertebrates (Snyder and Snyder, 1971; Kushlan, 1978). They are various shades of pink, orange and red in *Pomacea australis* (d'Orbigny), *Pomacea bridgesii* (Reeve), *P. canaliculata*, *P. dolioides* (possibly a synonym of *Pomacea lineata* (Spix) but considered distinct by Geijskes and Pain, 1957), *P. hanleyi* (Reeve), *P. insularum*, *P. lineata*, *Pomacea megastoma* (Sowerby), *P. paludosa* and *Pomacea sordida* (Swainson) (van Dinther, 1956, 1973; Snyder and Snyder, 1971; Thiengo, 1987, 1989; Winner, 1989, 1996; Keawjam and Upatham, 1990; Thiengo *et al.*, 1993; Perera and Walls, 1996). The eggs are green in *Pomacea glauca* (Linnaeus), *Pomacea pyrum* (Philippi), *Pomacea decussata* (Moricand) and *Pomacea nais* Pain (Pain, 1950b; van Dinther, 1956, 1973; Snyder and Snyder, 1971; Perera and Walls, 1996). Snyder and Snyder (1971) hesitated to consider green eggs to have evolved for camouflage because they generally remained distinctly visible, at least to humans. The eggs of *Pomacea falconensis* Pain & Arias, *Pomacea flagellata* (Say), *Pomacea gossei* (Reeve), *Pomacea fasciata* (Roissy) and *Pomacea cuprina* (Reeve) are white (Andrews, 1933; Snyder and Snyder, 1971; Perera and Walls, 1996). Eggs of *P. urceus* are reported as either white (Burky, 1973, 1974) or orange (Lum-Kong and Kenny, 1989) or to vary from orange to pale green (Perera and Walls, 1996); those of *P. haustrum* have been reported as both green (Winner, 1989, 1996) and red/pink (Snyder and Snyder, 1971; Guimarães, 1981a); in both cases this may represent taxonomic confusion. Comfort's (1947) report that the eggs of *P. glauca* are red is based on a misidentification of a species (perhaps *P. canaliculata*) from Argentina. Egg colour may change somewhat as the egg surface dries following oviposition and subsequently as the dark-coloured embryo develops inside (Snyder and Snyder, 1971).

The eggs of *Pila* and *Lanistes* are not brightly coloured. The colour of the eggs of *Asolene* have not been reported. Those of *Marisa* (at least *M. cornuarietis*) are orange when laid but soon lose this colour (Michelson, 1961); they were reported as 'grayish-white' by Robins (1971).

Growth and longevity

Little is known of these aspects of the biology of ampullariids (Table 5.1; see also Estebenet and Cazzaniga, 1992). A number of studies have investigated growth in the laboratory (Table 5.1), but it is difficult to relate these studies to growth in the wild. One laboratory study, on *P. canaliculata* in its native Argentina (Estebenet and Cazzaniga, 1992), did, however, demonstrate the crucial role of temperature in growth and reproduction. At a constant 25°C, *P. canaliculata* matured in 7 months, then bred continuously for a single 'season' of about 4 months and then died. In contrast, under seasonally fluctuating temperatures (7–28°C), *P. canaliculata* took 2 years to reach maturity; they then bred for two distinct annual breeding seasons, for a lifespan of about 4 years. In the wild in Argentina, *P. canaliculata* breeds only during the summer (Scott, 1957), and the life cycle under the fluctuating laboratory temperature regime may indeed approximate the life cycle under natural field conditions. Under semi-artificial conditions in Japan (an outdoor pond but with food provided), *P. canaliculata* grew to maturity in less than 2 months (Chang, 1985). In tropical regions of South-East Asia, release from the seasonality of its natural range may be at least one reason why *P. canaliculata* is so prolific; rapid growth and breeding, and hence rapid succession of generations, are permitted year-round (Naylor, 1996), leading to rapid population expansion and high abundance. A short life might then be predicted, but longevity in the field under such tropical conditions has not been reported.

A multitude of other biotic and abiotic factors may influence growth. For instance, the growth rate of *P. dolioides* in its native South America is determined by food availability, as well as by the quantity of water and the duration and intensity of the dry season (van Dinther, 1956, 1962; Donnay and Beissinger, 1993). And, as for other gastropod species, population density (Cameron and Carter, 1979; Cazzaniga and Estebenet, 1988) and both inter- and intraspecific competition may be important in growth regulation.

Maximum size varies greatly among populations (e.g. Keawjam, 1986; Estebenet and Cazzaniga, 1992; Donnay and Beissinger, 1993) and may be related to a number of environmental factors, including habitat size (Johnson, 1958), microclimatic variation and differing water regimes (Donnay and Beissinger, 1993) and population density. The maximum size of *P. canaliculata* in Hawaii is about 30 mm, but in Asia it can reach at least 65 mm (Schnorbach, 1995) or even 90 mm (Heidenreich *et al.*, 1997).

Population dynamics and abundance

Few studies have addressed ampullariid population dynamics directly. It is clear, however, that seasonal changes in water availability are important. In Florida, recruitment of *P. paludosa* was dramatically enhanced during years when the water-table remained high, allowing the animals to remain active instead of having to aestivate; larger animals were also thought to be more able to withstand dry periods (Kushlan, 1975). *P. urceus* will only enter aestivation once a shell length of 85 mm has been reached (Burky *et al.*, 1972). In Venezuela, habitats with more permanent standing water (rice-fields, as opposed to natural wetlands) allowed *P. dolioides* to grow larger and achieve higher abundance, essentially because the period spent in aestivation (no growth) was shorter; densities ranged from 3 100 m^{-2} in natural wetlands to 33 100 m^{-2} in rice-fields (Donnay and Beissinger, 1993). In Hawaii, recorded abundances of *P. canaliculata* in taro patches have exceeded 130 m^{-2} (12.9 ft^{-2}) (Tamaru, 1996; Tamaru and Hun, 1996). In rice paddies in the Philippines *P. canaliculata* abundance is generally 1–5 m^{-2} but densities up to 150 m^{-2} have been reported (Halwart, 1994a; Schnorbach, 1995). Anderson (1993), perhaps mistakenly, reported '1,000 mature snails per square metre' in the Philippines. In rice in Japan, population densities of 3–7 m^{-2} (Okuma *et al.*, 1994) and 12–19 m^{-2} (Litsinger and Estano, 1993) have been reported. Clearly, in irrigated systems with water present longer than would naturally be the case, *Pomacea* can reach maturity in a shorter period. Fluctuations in abundance in *P. haustrum* in Brazil (up to a maximum of 215 m^{-2}) were reported by Freitas *et al.* (1987), although the underlying reasons for the fluctuations were unclear. Again, numerous biotic and abiotic factors may be involved (Bryan, 1990; Perera and Yong, 1990). Over the reproductive season in Florida, *P. paludosa* populations were estimated to produce 1.2–1.5 million individuals ha^{-1} (= 120–150 m^{-2}) (Hanning, 1978).

M. cornuarietis, introduced to Florida, has been reported at densities over 200 m^{-2} (20.9 ft^{-2}) (Robins, 1971). *Lanistes nyassanus* Dohrn is found at densities of about 1 m^{-2} in Lake Malawi (Louda and McKaye, 1982). It is listed as an endangered species by the International Union for the Conservation of Nature (IUCN, 1996).

Clearly, following hatching, abundance in the immediate vicinity of the clutch will be high. However, few of the above reports are sufficiently detailed to assess the impact of survivorship on population densities, although clearly some species, especially when introduced, are able to achieve remarkably high adult abundances.

Natural enemies

Predators

Perhaps the best-known predator of New World ampullariids is the kite *Rostrhamus sociabilis* d'Orbigny (Accipitridae) (in Florida, known as the Everglade snail kite and considered endangered in the USA), which has a long, slender, hooked bill adapted for extracting gastropods from their shells (Pain, 1950b; van Dinther, 1956; Snyder and Snyder, 1971; Kushlan, 1975; Beissinger *et al.*, 1994). In Florida, the kite's natural prey is *P. paludosa*; in South America it preys on a number of other species:

P. lineata, *P. dolioides*, *Pomacea papyracea* (Spix) and *M. cornuarietis*. Another important New World avian predator is the limpkin (*Aramus guarauna* d'Orbigny) (Aramidae), a large wading bird similar to an ibis. Limpkins are found virtually throughout the New World distribution of ampullariids, which constitute a major part of their diet (Peterson, 1980). Caiman lizards (*Dracaena guianensis* Daudin) feed almost exclusively on ampullariids; their teeth have evolved into rounded knobs for crushing gastropod shells (Perera and Walls, 1996). Other predators include various birds, crocodilians, fishes, turtles, crayfish and aquatic insects (Robins, 1971; Snyder and Snyder, 1971; Kushlan, 1975; Donnay and Beissinger, 1993). However, insufficient work has been done to evaluate whether any of these predators have a significant impact on ampullariid population dynamics (Donnay and Beissinger, 1993). In Africa, species of *Lanistes* are a major food resource of various species of fish, which may exert significant selection pressure on shell morphology (Louda and McKaye, 1982), but their impact, if any, on population dynamics is unknown.

Some species (*P. paludosa* and, to a lesser degree, *P. glauca* and *P. dolioides*) exhibit an alarm response on detecting chemical stimuli in the water from predators (turtles) or the juices of damaged conspecifics (Snyder and Snyder, 1971) and in response to mechanical disturbance of vegetation they are sitting on (Perry, 1974). The animals drop to the substrate (if they are not already on it) and bury themselves in it.

Parasites and pathogens

Little has been published in this area. Various ampullariid species are vectors of metastrongylid nematodes, including *Angiostrongylus cantonensis* (Chen), and various trematodes, including schistosomes (see below). The importance of these parasites in ampullariid population dynamics is at present unknown. Three species of temnocephalid flatworms are reported to live symbiotically in the mantle cavity of species of *Pomacea* and *Asolene* in South America (de León, 1989). Whether any of these parasites cause harm to the ampullariid host is unknown. There appears to be no knowledge of natural microbial pathogens in apple snails, although other gastropods are known to be associated with microorganisms such as protozoa, both as parasites and as symbionts or commensals (Godan, 1983). Again, whether any of these parasites or pathogens play (or could play) a role in population regulation is unknown.

Food and feeding

The feeding habits of ampullariids are microphagous, zoophagous and macrophytophagous, none being mutually exclusive (Estebenet, 1995). Ciliary feeding on particulate matter on the water surface has been described for some species (McClary, 1964). Some species will feed on insects, crustaceans, small fish, etc., mostly as carrion but not always so (McLane, 1939; Estebenet, 1995). Some species (e.g. *M. cornuarietis*, *P. canaliculata*) will attack other gastropods and their eggs (Demian and Lutfy, 1966; Robins, 1971; Aldridge, 1983; Cedeño-León and Thomas, 1983; Cazzaniga, 1990b). The predominant habit, however, is macrophytophagous, which from an agricultural pest standpoint is also the most significant. Andrews (1965a) described the feeding behaviour of *P. canaliculata* in detail. This species shows preferences among different food plants; its rate of growth correlates with its feeding on a preferred plant; and it is able to detect its food plants from some distance, using chemical cues in the water (Estebenet, 1995; Lach *et al.*, 2001), as can *P. paludosa* (McClary, 1964). However, despite exhibiting such preferences, *P. canaliculata* appears to be somewhat of a generalist and indiscriminate (e.g. Schnorbach, 1995), and, as suggested for *M. cornuarietis* by Robins (1971), it may be 'more pertinent to determine what the animal does not eat than what it will eat'. In fact, anecdotal comments suggest that *P. canaliculata* is particularly voracious compared with other ampullariids (Neck, 1986).

Respiration

Many ampullariids are amphibious, in both physiology and behaviour. The mantle cavity contains both a ctenidium ('gill') and a portion modified as a pulmonary sack or 'lung' (Andrews, 1965b). In *P. urceus* in Venezuela (Burky and Burky, 1977), ventilation of the lung by extending the siphon to the water surface occurs periodically, and more frequently under conditions of low oxygen tension. Ventilation of the lung, as well as being used for respiration, is also used to adjust buoyancy levels, such that *P. urceus* can float at the water surface under periods of low oxygen tension. Burky and Burky (1977) reported similar patterns of ventilation for *P. falconensis*, *Pomacea luteostoma* (Swainson) and *M. cornuarietis*, with smaller animals (including juvenile *P. urceus*) ventilating more frequently than larger ones, probably reflecting differences in lung capacity relative to body weight and metabolic rate. Lung ventilation is obligatory, but the animals can nevertheless survive extended periods without active intake of air: up to 6 h in *P. lineata* (van Dinther, 1956). Similar respiratory behaviour has been described for other ampullariids (McClary, 1964; Freiburg and Hazelwood, 1977), with differences among species in the relative significance of aerial and aquatic respiration (Andrews, 1965b). Work on respiration rate and its relation to temperature and oxygen tension has been reviewed by Aldridge (1983) and Santos *et al.* (1987). The ability to use the ctenidia and the 'lung' for respiration allows many ampullariids to survive significant periods out of water and to disperse significant distances over land. This is clearly of adaptive value for species that live in marshy or other habitats that dry out periodically. It also means that when introduced to new habitats, such as rice paddies or taro patches, the animals may be difficult to contain within circumscribed areas as they may easily cross the raised burms between paddies (although this has been reported as not occurring (Eversole, 1992)).

Aestivation

Many ampullariids aestivate during dry periods (Lum-Kong and Kenny, 1989). When the animals' habitat dries out, they bury themselves in the mud. Some species (e.g. *P. urceus*) bury themselves only superficially, with part of the shell remaining above the surface of the hardened mud (Burky *et al.*, 1972); others bury up to 1 m deep (e.g. *Pila ampullacea* (Linnaeus), *Pila pesmei* (Morelet)) (see Keawjam, 1986)). They can survive in this state in some cases for extended periods (in laboratory experiments), far longer than are likely to be necessary in the wild, e.g. 8 months for *P. glauca* (van Dinther, 1956), 13 months for *P. lineata* (Little, 1968), 17 months for *P. urceus* (Burky *et al.*, 1972), at least a year for *P. ampullacea* and *P. pesmei* (Keawjam, 1986) and 25 months for *P. globosa* (Chandrasekharam *et al.*, 1982). *P. canaliculata* is reported to survive buried in the earth only up to 3 months (Schnorbach, 1995). They can withstand significant loss of soft-tissue weight during aestivation; in *P. lineata* up to 50% (Little, 1968) and in *P. urceus* up to 62% (Burky *et al.*, 1972). *Pila virens* (de Lamarck) and *P. globosa* lose considerably less weight (5%) but can nevertheless aestivate for at least 6 months; the shell and operculum appear to be effective barriers to water loss, especially as the operculum is sealed in the shell aperture with dried mucus (Meenakshi, 1964). Metabolism during aestivation is anaerobic in *P. virens* and *P. globosa* (Meenakshi, 1964; Aldridge, 1983), but aerobic in *P. ovata* (Olivier) and *P. urceus* (Burky *et al.*, 1972). *P. virens* and *P. globosa* (and other species of *Pila*) aestivate buried very deep in the ground; their anaerobic aestivation metabolism may be an adaptation to this, in contrast to the aerobic respiration of the shallow-burying *P. urceus*. Metabolism during aestivation in *M. cornuarietis* has been described by Horne (1979); this species tolerates anaerobic conditions only for about 48 h. However, adult *M. cornuarietis* can withstand at least 30 days out of water in 20% relative humidity or 120 days at 80% relative humidity, although juveniles have little resistance to desiccation (Robins, 1971).

Physiology

Lethal temperatures

During aestivation, *P. urceus* regulates its body temperature below 41°C, in part through evaporative cooling; this species has an upper lethal temperature between 40 and 45°C (Burky *et al.*, 1972). Adult *P. urceus* are more tolerant of high temperature than are juveniles (Burky *et al.*, 1972), perhaps because adults can afford to lose more water through evaporative cooling (cf. Cowie, 1985). In both *P. paludosa* and *M. cornuarietis*, 40°C is lethal when animals are exposed for 1–4 h (Freiburg and Hazelwood, 1977), although Thomas (1975) reported that they could withstand temperatures up to 45°C. Robins (1971) gave 39°C as the 'upper limit of short-term heat tolerance' for *M. cornuarietis*, with juveniles more tolerant than adults at 37°C and both adults and juveniles feeding normally between 33.5 and 35.5°C; eggs did not develop normally at 35–37°C. Mochida (1991) reported for *P. canaliculata* that mortality is high at water temperatures above 32°C (35°C in Mochida (1988b) and Eversole (1992)). *P. virens* and *P. globosa* cannot survive for 2 days at 40°C (Meenakshi, 1964). *P. lineata* survived 1 h exposure at 40°C (Santos *et al.*, 1987).

Regarding low-temperature tolerance, Robins (1971) (see also Neck, 1984) reported that *M. cornuarietis* could survive for over 24 h at 11°C (although egg development ceased at this temperature), but succumbed in 5 h when exposed to 8°C – although Thomas (1975) reported that it could withstand 6°C. *P. paludosa* can survive exposure at 5°C (Freiburg and Hazelwood, 1977). Mochida (1991) reported *P. canaliculata* survival for 15–20 days at 0°C, 2 days at – 3°C, but only 6 h at – 6°C (see also Neck and Schultz, 1992; Wada, 1997). *P. lineata* survived 1 h exposure at 5°C (Santos *et al.*, 1987). *P. virens* and *P. globosa* cannot survive for 4 days at 20°C and die within 1 day at 10°C (Meenakshi, 1964).

Differences among species in both their upper and lower lethal limits may reflect adaptation to their natural climatic environment. There appears to be less variability in the upper limit, which in general appears to be around 40°C for many aquatic organisms. Comparability among the studies mentioned above is poor, however, largely because experimental procedures differed. Nevertheless, *P. canaliculata*, of more temperate habitats (Argentina), seems to have lower tolerance to high temperatures than more tropical species, such as *P. urceus*, *M. cornuarietis* and the two *Pila* species. Lower temprerature limits seem more variable, with *P. canaliculata* able to tolerate freezing temperatures, in marked contrast to the *Pila* species, which are unable to survive at 20°C beyond a few days. These differences probably have significant consequences for the potential establishment, reproduction, growth and population dynamics of apple snails when they are introduced to new regions with climates differing from those in their natural ranges.

Salinity tolerance

M. cornuarietis can withstand up to about 30% salt water (Hunt, 1961; Robins, 1971; Santos *et al.*, 1987). *P. globosa* can 'live in salt water of low salinity' (Prashad, 1925b). Fujio *et al.* (1991a) indicated differences in salinity tolerance among three 'strains' of *P. canaliculata*. Preliminary observations in Hawaii suggest that *P. canaliculata* is sufficiently tolerant of sea water to survive long enough to be carried by currents from one stream mouth to another, thereby providing for expansion of its distribution (F. Reppun and N. Reppun, personal communication, 1997). However, although exhibiting some tolerance of salinity, ampullariids generally live only in fresh water, and brackish water may limit the spread of some species (e.g. *M. cornuarietis* (Robins, 1971)).

Dispersal

Adult *P. lineata* travel several metres an hour (van Dinther, 1956). *L. nyassanus* moves an average 2.8 m day^{-1} (Louda and McKaye, 1982). *P. globosa* makes long excursions on land both for going from one source of water to another and for the purpose of laying eggs (Prashad, 1925b). Short-term dispersal activity, however, does not necessarily translate into long-term, long-distance dispersal. There is little documentation of the spread of ampullariids from a focus of introduction. In a canal in Florida, an introduced population of *M. cornuarietis* expanded by at least 1.5 km downstream in 6–8 months (Hunt, 1958) and within 12 years had become distributed in virtually the entire freshwater canal system in the Miami area, dispersal being predominantly by floating downstream on vegetation (Robins, 1971). Floating downstream (unattached to vegetation) has been seen in Hawaii and no doubt facilitates rapid dispersal, but crawling upstream is also possible (H. Ako, personal communication, 1997). However, the rapid dispersal of *P. canaliculata* within countries in South-East Asia, following its initial introduction, has been predominantly human-mediated.

Introductions

Distribution as a food item

A number of ampullariids are used as human food in their native ranges. For instance, *P. urceus* is eaten in Trinidad (Lum-Kong, 1989; Lum-Kong and Kenny, 1989) and in times of food scarcity in Guyana (Pain, 1950b). In India, *P. globosa* is eaten (Thomas, 1975), as are *Pila conica* (Wood) in Malaysia (Johnson, 1958), *Pila luzonica* (Reeve) in the Philippines (Palomino and Jueco, 1983) and native species of *Pila* in Thailand (Keawjam, 1986, 1990). Elsewhere in South-East Asia, ampullariids may be only a minor part of the local diet (e.g. in Cambodia (Cowie, 1995a)). In Africa, *Pila congoensis* Pilsbry & Bequaert was eaten, although only by older people because eating snails was thought to cause 'infecundity' (Pilsbry and Bequaert, 1927).

In both Guam (first reported in 1984) and Hawaii (first recorded in 1966) *P. conica* was introduced without authorization, either accidentally or deliberately as a food item (Smith, 1992; Cowie, 1995b). It was introduced to Palau in 1984 or 1985 but was thought to have been eradicated by 1987 (Eldredge, 1994).

Between 1979 and 1981 a species of *Pomacea*, usually referred to as *P. canaliculata*, was introduced to South-East Asia, initially from Argentina to Taiwan (e.g. Mochida, 1988a,b, 1991; Cheng, 1989 (as '*Pomacea lineata*')). The initial introduction to Taiwan was illegal (Cheng, 1989). The purpose of the introduction was both for local consumption and for development for export to the gourmet restaurant trade, with the expectation of high profits (Acosta and Pullin, 1991; Naylor, 1996). Prior marketing research had not been undertaken. The subsequent spread of this ampullariid, distributed for the same purposes and still with no market research, has been summarized by Mochida (1991), Litsinger and Estano (1993), Halwart (1994a), Naylor (1996) and Vitousek *et al.* (1996). In 1981 they were taken from Taiwan to Japan (they were present in Okinawa by at least 1984 (Fujio *et al.*, 1991a; Wada, 1997)), and by 1983 about 500 apple snail businesses had been established in various parts of Japan (Wada, 1997). In either 1980 or 1982 these apple snails were introduced from Taiwan to the Philippines (Mochida, 1991; Anderson, 1993; Halwart, 1994a; Joshi *et al.*, 2001), and introductions to the Philippines continued from various sources (and possibly including more than one species (Mochida, 1988b)) as snail-farming was promoted by both governmental and non-governmental organizations (Anderson, 1993). Later, *Pomacea* were taken to China (1985), Korea (probably 1986), parts of Malaysia (Sarawak and Peninsular Malaysia, 1987), Indonesia (Java and Sumatra, 1989), Thailand (1989), Vietnam (1988 or 1989) and Laos (1992). They have also been introduced to Hong Kong (Laup, 1991), Cambodia (Cowie, 1995a), Singapore (Ng *et al.*, 1993), Guam (from Taiwan (Smith, 1992; Eldredge, 1994), Papua New Guinea (from the Philippines (Laup, 1991 (as '*P. lineata*'); Anon., 1993; Eldredge, 1994)) and Hawaii (Cowie, 1995b, 1997b).

However, the ampullariids' economic potential seems to have been overestimated and no major trade based on aquaculture operations has developed (Acosta and Pullin, 1991). In Taiwan, failure of the local market was said to be because consumers did not like the 'tough meat and repulsive taste' (Chang, 1985; see also Cheng, 1989; Naylor, 1996; Vitousek *et al.*, 1996). In addition, developed nations maintain stringent health regulations that have largely precluded importation of *Pomacea* products (Anderson, 1993; Naylor, 1996). Animals escaped or were deliberately released from captivity and *Pomacea* has since become widespread and abundant in many countries. Expansion of their distribution has been assisted by, among other things, floods and typhoons, movement of infested soil during new paddy preparation, deliberate release of animals for weed control and their use for fishing bait (Anderson, 1993; Wada, 1997).

Appendix C:

Source by permission: E kūpaku ka 'āina. Pālolo Invasive Species Swat Team Project.
Example invasive species mini-curriculum.

What is an Invasive Species?

Executive Order 13112 signed on February 3, 1999 by the President of the United States defines an invasive species as:

- An *alien species* whose introduction does or is *likely to cause* economic or environmental *harm* or harm to human health.

- An “alien species’’ is, with respect to a particular ecosystem, *any species*, including its seeds, eggs, spores, or other biological material capable of propagating that species, *that is not native to that ecosystem*.

Hawai'i has the highest number of endemic species in the United States. It also has the highest rate of endemic threatened and endangered species and extinctions in the U.S.

Pālolo Invasive Species Swat Team (PISST). A project funded by the Hawai'i Invasive Species Council (HISC) and sponsored by E kūpaku ka 'āina – The Hawai'i Land Restoration Institute. P.O. Box 2832, Wailuku HI 96793.

Capable Colonizers

Can establish themselves and thrive in a variety of climates and ecosystems including harsh conditions such as droughts, degraded soils, and a range of water temperatures and salinity. They may out-shade, out-compete, and out-eat native species, or even send out chemical messages to other species to stay away. Apple snails, tilapia, fire ants, kudzu vine, ironwood, and koa haole are examples.

Ironwoods taking over a beach

Kudzu smothering the trees

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Prolific Producers


Apple snail eggs on a taro plant

Hundreds or thousands of seeds, eggs or young produced in each cycle; sometimes more than one cycle in a year.

Fountain grass


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Resilient Roots

Plants with tough, extensive root systems that can withstand drought, disease, and are hard to kill, resprouting over and over again, such as Surinam cherry, gorse, kahili ginger and strawberry guava.


Strawberry guava


Kahili ginger

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Serious Seeds

Can survive all kinds of conditions, including passing through the stomach of an animal or bird because of protective seed coats. Good germination and survival rates.   For example, Koa haole (*Leuceana leucocephala*) seeds get moved around by birds, animals, and moving soils and remain viable (able to sprout) in the soil for at least a decade.


Koa haole

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Tricky Travelers

Seeds or young that move around easily – "hitchhikers" like sandburs and kinehe that can grab on to your pants as you hike and organisms that can attach to a boat; light-weight seeds or young that can be moved by wind or water easily such as alien corals like *Carijoa riisei* (snowflake coral), tiny insects, or fountain grass; seeds with hard shells that move with soil movement or get deposited from place to place through the stomach of an animal.


Glassy-winged sharpshooter


Snowflake coral

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Earn a P.I.S.S.T. Badge!*

1. Fill out a membership application and take a mini-quiz on invasive species.
2. Complete the following activities by:___________
   a) Learn **the difference** between the words *endemic*, *indigenous*, *Polynesian-introduced*, *native*, *non-native*, *alien* and *invasive*.
   b) Learn **the characteristics** that make a plant, animal, or insect invasive.
   c) Learn **the names** of the **O'ahu Invasive Species Committee** target species list and what they look like.
   http://www.hear.org/oisc/oisc_target_species/index.html
   d) Learn **the three steps** to prevent alien species from spreading.
   e) **In your own home** - Select 5 different plants in your yard and find out:
      - What is the common name of each plant?
      - What is the scientific name of each plant?
      - What was the country of origin (where is each plant's *real* home)?
      - How many miles did each plant travel to arrive in Hawai'i?

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f) **Participate** in at least 1 invasive species, trail or stream cleanup event with the P.I.S.S.T., OISC, Sierra Club, the Nature Conservancy, your school or a community group within the ahupua'a of Pālolo (area from Ka'au Crater to the coast of Diamond Head).

3. Return in your Achievement Pages to the P.I.S.S.T. Assistant Coordinator and take a final mini-quiz and you've earned a badge!

The skills you will need:

- Reading comprehension
- Investigative research
- Observation
- Thinking
- Willingness to join in and work

* *Any age can participate but you should be able to read and write clearly and old enough to participate in a work day. We recommend that you be in at least 5-6th grade.*

[A badge program is just one example of the kinds of encouragement you can provide to students to engage them in being part of invasive species efforts in Hawai'i.]

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Definitions:

Name: ____

Date: __________________

Define the following words *as it relates to plants and animals* in Hawai'i.

Endemic:

Indigenous:

Polynesian-introduced:

Native:

Non-native:

Alien:

Invasive:

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Characteristics:

Name: ____

Date: ____________________

Describe the characteristics of an invasive species.

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O'ahu Invasive Species Targets:

Name: ____

Date: _________________

Fill in the names of the invasive species shown below.

A.

B.

C.

D.

E.

F.

A.__________________________ B.____________________________

C.__________________________ D.____________________________

E.__________________________ F.____________________________

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Prevention:

Name: ____

Date: ____________________

Hawai'i has 3 main messages about preventing the spread of an invasive species. Answer the questions below about these messages.

<u>Don't Pack A Pest</u>

1. What can you do to prevent packing a pest when you go hiking?

2. What should you do to prevent packing a pest into Hawai'i or between islands?

<u>Don't Plant A Pest</u>

1. What *shouldn't* you do if you have an aquarium animal you don't want anymore?

2. What kinds of plants would you choose for your yard to prevent the spread of invasive species in Pālolo Valley?

<u>Report A Pest</u>

1. What number can you call to report an invasive species on any island?

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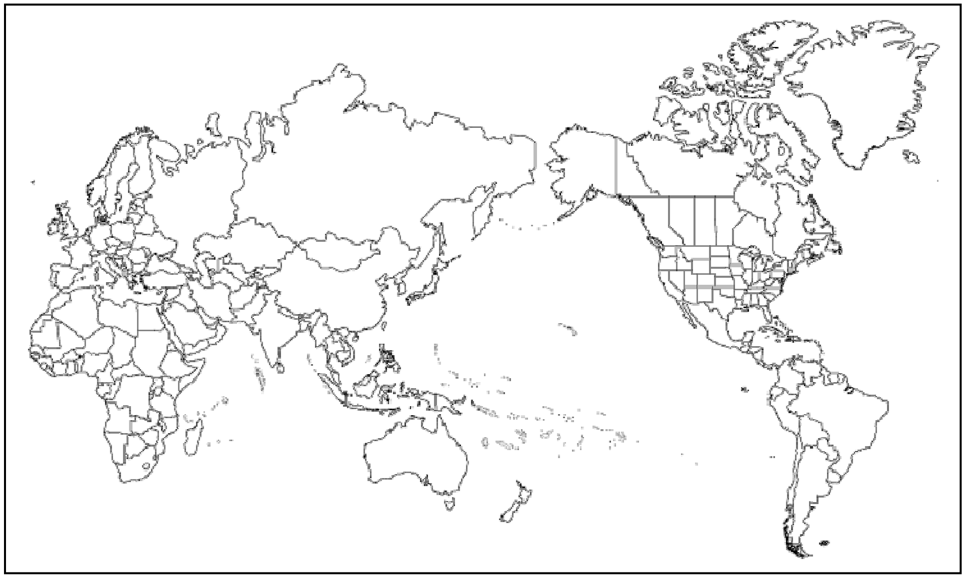
In Your Own Home:

Name: ____

Date: __________________

Name the 5 plants you researched in your yard. Put one colored dot on the map for each Country of Origin. Record how many miles each plant traveled to arrive in Hawai'i.

Common Name	*Scientific Name*	Distance from Hawai'i



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Participation:

Participant's Name: ____

Date: ___________________________________

Work Site: _______________________________

Activity: ________________________________

I verify that_____________________________has participated in an invasive species, trail or stream cleanup work day with the organization/project

____on the date of

______________________________________ for ____hours.

Name (print):______________________________
Project Organizer

Signature: ________________________________

Contact Information:
Phone:

Email:

Organization address:

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P.I.S.S.T. Mini Quiz 1.

Name: ___________________________________

Date: ___________________________________

1. What is an alien species?

2. Describes the qualities (characteristics) that make an alien plant, animal or insect invasive:

3. Name 1 invasive plant or animal found on land, in local streams, and in the ocean in Hawai'i:

On land: ____________________________________

In streams: ____________________________________

In the ocean: ____________________________________

3. Name 1 invasive species found in Pālolo Valley.

4. How do you think some invasive species get to Hawai'i?

5. Name 3 ways to prevent the spread of invasive species?

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