Affect of Land Management Practices on Hawaiian Stilt Population Abundance at Nuupia Ponds Wildlife Management Area, Oahu, Hawaii

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Abstract. The Nuupia Wildlife Management Area (WMA) is home to 10 percent of Hawaii's population of the endangered *Himantopus mexicanus knudseni (Ae'o* or Hawaiian Stilt). The Hawaiian Stilt prefers tidal mudflats for foraging and nesting. These habitats have been increasing threatened by invasive plant species that render the mudflats unsuitable for Hawaiian Stilt nesting and foraging. For more than 25-years management efforts of the Nuupia ponds have targeted invasive species in order to maintain land cover type suitable for the Hawaiian Stilt. Annual efforts to control *Batis maritime* (pickleweed) before the nesting season created ideal nesting habitat for the Hawaiian Stilt. In addition, 20-years of eradication efforts, have removed the majority of *Rhizophora mangle* (red mangrove) from the Nuupia ponds increasing suitable nesting and foraging areas for the Hawaiian Stilt. These efforts and others have benefited the Hawaiian Stilt at Nuupia ponds, whose population has more than doubled since these management practices were implemented.

Key Words: Hawaiian Stilt, management, military conservation, pickleweed, red mangrove

Introduction

The Hawaiian Stilt is an endangered endemic waterbird found throughout the state of Hawaii with primary populations on the islands of Kauai, Maui, and Oahu (Engilis and Pratt, 1993). The populations on Oahu are believed to migrate between Maui, Lanai, and Molokai. The larger populations on Maui and Oahu often serve as population sources for the small populations on Lanai when they become locally extinct.

Stilts were hunted legally until the early 1940s when the statewide population was believed to be approximately 200 individuals (Reed, 1998).

On the island of Oahu, numerous wetlands provide suitable habitat. During the winter months, rainy weather creates seasonal wetlands that stilts will disperse to. When these patches dry up, stilts return to the primary wetlands. Of these wetlands on Oahu, one of the prime stilt nesting areas is at Nuupia Wildlife Management Area (WMA) (Shallenberger, 1977). The Nuupia WMA also contain optimum stilt habitat that is open mudflats with water depths of 13 cm or less and ponds of variable salinity (Rauzon and Drigot, 2002).

The Hawaiian Stilt population at Nuupia WMA has gradually increased since counts were started there (Table 1). The general trend of these counts has been a steady population through the 1960s with a gradual increase in population starting in the 1970s to the present. The Nuupia WMA currently contain approximately 10% of the state of Hawaii's Hawaiian Stilt Population (Rauzon, 2002).

Threats to the Hawaiian Stilt

Primary threats to the Hawaiian Stilt come in the form of predation by invasive mongoose, feral cats and dogs, and night-herons, and by habitat loss due to the invasive plant species, pickleweed, and red mangrove (Rauzon and Drigot, 2002; Reed, 1997). As Shallenberger noted in the 1970s (1977), despite aggressive predator control methods at Nuupia ponds, it appeared these efforts were futile in reducing predation on the birds. In addition, Reed (1998) stated that based on population viability analysis, the Hawaiian

Stilt could not be self-sustaining and downgraded from endangered species status unless all invasive predators and wetland plants were removed from the Hawaiian Islands.

Invasive red mangrove and pickleweed deprive the stilts of both foraging and nesting areas. The red mangrove first entered the Nuupia ponds in the 1970s, becoming a pest species by 1974. The red mangrove covers intertidal soft substrate extending the pond's margins, raising the acidity, temperature, and salinity levels, and reducing dissolved oxygen. Pickleweed creates low, thick, dense vegetation mats, a condition not optimal for the Hawaiian Stilt. Both of these plants deprive the stilts of both foraging and nesting areas (Rauzon and Drigot, 2002; Reed, 1997; Allen, 1998).

The Sikes Act of 1960 and the Sikes Improvement Act of 1997 established conservation efforts on Department of Defense (DoD) installations. These acts, among other purposes, charge the US armed forces with "the conservation and rehabilitation of natural resources on military installations" (H.R. 1119, 1997). While the nature of certain military training appears to be at odds with natural resource management, the DoD has come to understand the importance of maintaining environmentally healthy facilities (NatureServe, 2008). With increased development at their peripheries, preservation of wilderness for training has also maintained a landscape and biodiversity that no longer exists in the surrounding community. Thus their cooperation has become extremely important for the continued survival of numerous endangered species.

The Environmental Section of Marine Corps Base Hawaii Kaneohe Bay manages the Nuupia WMA as a wildlife refuge area. In addition to the Sikes Act, base conservation and natural resource management efforts are guided by other federal and state regulations. Since 1966, the base has operated in coordination with numerous state agencies to manage fish and wildlife natural resources, and since 1970, the base has received numerous awards in recognition of its natural resources program (Drigot, 2001).

Nuupia ponds, with the wetlands at Pearl Harbor, was considered by Shallenberger as the prime stilt nesting areas on Oahu (1977). Despite this appellation, Hawaiian Stilt population at the Nuupia ponds remained relatively stable, with only marginal increases, from the 1950s through the 1970s. It appeared extensive cooperative conservation efforts between the base and state and federal agencies appeared to have no positive impact on the population during this time. It appeared that numerous factors were limiting the Hawaiian Stilts success to include mongoose predation, and increased red mangroves in the western ponds. Positively, he added that limited military amphibious assault vehicle (AAV) training in the ponds created furrows in the mud flats, which were ideal nesting sites for the Hawaiian Stilt, and cleared pickleweed from the habitat. The greatest value of the Nuupia ponds, he believed, lay in their potential (Shallenberger, 1977).

Management Practices

The Nuupia Ponds WMA is managed primarily for the Hawaiian Stilt but other waterbirds and migratory birds use ponds to include the Hawaiian Coot, Hawaiian Gallinule, Hawaiian duck, night herons, Pintail ducks, and many more (Shallenberger, 1977; Drigot, 2001). In order to control these threats to the Hawaiian Stilt and create suitable habitat at Nuupia ponds, managers have engaged in multiple efforts to mitigate predation, remove invasive plant species, and temporarily modify the mudflat vegetation cover (Table 2). These efforts include predator trapping and hunting, and invasive plant

control through community events, military training, and extensive plant removal projects.

In 1983, there were estimated to be 20-acres of red mangrove mainly occurring in the western ponds of the WMA. Initial management efforts in the 1980s recruited volunteers to pull mangroves by hand and by 1990 they had cleared approximately 2-acres of red mangrove. Eradication efforts increased throughout the 1990s centering on base and volunteer “weed pulls” (Drigot, 2007) and contracted mangrove removal projects. The weed pulls organized local and base personnel to remove younger mangroves, mangroves infestations along the archeologically important fishpond walls, and propagules. These small-scale projects prevented mangrove establishment in new parts of the WMA, and reestablishment in areas previously cleared. MCBH also conducted three removal projects in the 1990s that mechanically cleared an additional 20-acres of from the WMA (Drigot, 2001). By 2000, nearly all red mangrove had been removed from the WMA (Rauzon, 2002).

Pickleweed is an invasive species that can cover nearly all of the tidal mudflats if left unchecked. Military training in the mudflats was limited in the 1970s, but it appeared the 26-ton amphibious assault vehicle (AAV) training cleared areas of the mudflats of pickleweed and an experimental program using the AAVs to manipulate the conditions of the mudflats might be productive (Shallenberger, 1977). In 1982, WMA managers, in coordination with the Marines at Kaneohe, used the AAVs to clear areas of the mudflats of pickleweed prior to the summer nesting season and have continued with the practice annually. While actual locations vary, the AAVs are used to plow approximately 5 ha (≈12.4 acres) of pickleweed in differing patterns that create checkerboard, moat and island, and doughnut-like patterns in the mudflats (Figure 1, 2) (Drigot, 2007). These operations disrupted the pickleweed rootstock, which would then take from months to years to reestablish and also appear to created attractive nesting conditions for the stilt. Hawaiian Stilts appear to occupy the areas that are cleared of both pickleweed and red mangrove (Figures 3, 4, 5).

Predator trapping has been conducted at the WMA since 1971. Efforts have targeted numerous feral species to include cats (*Felis cattus*), Indian Mongoose (*Herpestes javanicus,* former *H. auropunctatus*), Black Rat or Roof Rat (*Rattus rattus*), and the House Mouse (*Mus musculus*) (Volinski, 2007). (Shallenberger, 1977; Volinski, 2007; Rauzon, 2002). While predator trapping appears to be targeting the species, there was insufficient data over time to analyze and correlate to population abundance .

The purpose of this paper is to determine whether management practices at the Nuupia WMA to control the spread of red mangrove and pickleweed and maintain tidal mudflats, land cover favorable to the Hawaiian Stilt, have been effective and are responsible for the increase in Hawaiian Stilt abundance observed there over the past 25-years.

Methods

Study Site

The Nuupia wetlands is a 515-acre designated wildlife management area (WMA) located on Marine Corps Base Hawaii Kaneohe Bay straddling the narrow neck of Mokapu Peninsula on the windward side of the island of Oahu (Figures 6,7) (Aecos, 1983). The wetlands consist of eight shallow ponds with surface areas totaling 237-acres,

and surrounding wetlands with surface areas totaling 278-acres. The ponds depths are tidally influenced with average depths between 12 and 27 cm, and interconnected by channels and culverts. Three sets of 122-cm diameter and two sets of 60-cm diameter concrete pipes under the H-3 Highway connect the western most pond, Nuupia Ekahi, with Kaneohe Bay. During high tides, the eastern side of the WMA, Pa'akai, is connected to Kailua Bay by a long channel (Schallenberger, 1977).

Native Hawaiians historically used the western ponds as fisheries, and the eastern pond, Pa'akai, to manufacture salt, although their margins have been extensively modified over the years. Throughout the pond system there still exist remnant dividing stonewalls built by these early Polynesian (Cox and Jokiel, 1997). Preservation of these walls has influenced management practices implemented to clear red mangrove from certain parts of the Nuupia WMA.

Stilt Count Methodology

Hawaiian Stilt abundance data was obtained from Audubon Society between 1947 and 1960. Between 1961 and 2006, abundance data was obtained the average of Audubon and Department of Land and Natural Resource's (DLNR) counts. The Audubon Society conducts a bird count every Christmas, while the DLNR conducts counts every December and August. The count methodologies are similar, with a few differences. DLNR focuses specifically on *Fulicia Americana alai* (Hawaiian Coot), the Hawaiian Stilt, *Gallinula chloropus sandvicensis* (Moorhen), and *Anas wyvillaina* (Hawaiian Duck) on all Hawaiian wetlands. Their counts on MCBH Kaneohe include the entire Nuupia WMA (Figure 8). The Audubon Society counts all birds in prescribed 15-

mile circles that cover all of MCBH Kaneohe Bay (Figure 8) and is not restricted to wetlands only. Hawaiian Stilts are occasionally seen away from the wetlands, but in small numbers. The results from the Audubon Society and DLNR counts are comparable (Vanderwerf, 2008).

Data Analysis

ANOVA analysis of population average from 1947-2005 was conducted using an on-line statistics tool from the College of St. Benedict St. John's University (CSBJU, 2008). Hawaiian Stilt abundance was compared in 10-year groups from 1947-2005 to see change over time without regard to management pratice (Figure 10). Abundance in 17-year increment were also analyzed to compare periods with no management in the 1940s and 1950s, minimal management throughouth the late 1960s and 1970s, and increased management during the 1980s to present (Figure 11). Abundance was also analyzed in pre-1982 minimal management to compare the no-management period of the 1940s and 1950s, the minimal management of the 1960s and the relatively increased management in the 1970s (Figure 12). Post-1982 abundance was also analyzed with periods reflecting 1) AAV ops and weed pulls, 2) mechanical red mangrove removal, AAV ops, and weed pulls, and 3) maintenance period when most red mangroves had been removed, AAV ops, and weed pulls (Figure 13).

Results

After management practices were adopted, in the 1980s, there is a dramatic increase in bird count averages. All ANOVA analyses were negative for the null

hypothesis. The first analysis of 10-year increments ($F(5,52) = 22.84$, $p < .0001$) indicating that average bird count over 10-year periods varied greatly and the change was unlikely due to chance. The second analysis with two periods pre-management and one post management ($F(2,55) = 32.90$, $p < .0001$) showed a positive increase in averages during post management periods, and this increase is also very unlikely due to chance. The pre-1982 analysis ($F(2,33) = 3.682$, $p = .036$), indicated that there was an increase in averages during the 1970s compared to previous years. The post-1982 analysis ($F(2,23) = 7.736$, $p = .0032$) showed great variation between the three groups but on an upward trend.

Discussion

Based on the ANOVA analysis, consistent trends can be seen. It appears that predator control and limited AAV training during the 1970s had a positive effect on Hawaiian Stilt population at Nuupia WMA. AAV pickleweed clearing and limited red mangrove clearing in the 1980s also resulted in additional rise in stilt abundance. The the impact of mechanical red mangrove clearing in the 1990s appears to have the greatest impact on Hawaiian Stilt Abundance. There is an immediate rise in stilt population that was maintained by propagule clearing and continued AAV operations from 1998-2005.

Direct management of the tidal mudflats to maintain a habitat suitable for the Hawaiian Stilt has been successful. In order to maintain the Nuupia WMA as suitable habitat for the Hawaiian Stilt, managers at MCBH must continue AAV operations and community weed pulls to keep pickleweed under control, and to prevent red mangrove propagules from reestablishing on the mudflat margins. Without these management techniques, the continuous presence of invasive plant species could limit suitable habitat at Nuupia WMA endangering the success it is currently seeing as a sanctuary for the Hawaiian Stilt and other Hawaiian waterbirds. The maintenance of current suitable habitat for the Hawaiian Stilt throughout the Islands of Hawaii is imperative for their long-term success (Reed, 1998) and the Marines at Kaneohe have proven Shallenberger's observations in 1977 correct: there was much greater potential for the Hawaiian Stilt at Nuupia WMA.

Tables

1. Stilt population counts. Counts are derived from annual Audubon Society counts which date back to 1947, and Department of Land and Natural Resources (DLNR) counts that date back to 1961. In 1970 DLNR started semi-annual counts.
2. Management Practices Table. Management practice and period implemented.

Figures

1. Diagram of mangrove to be removed in 1994 1995. Note the mud flats are indicated as covered in Pickleweed.

2. Doughnut-like and checkerboard patterns created by AAV operations are clearly visible on tidal flats of Halekou and Nuupia Ekolu ponds in this satellite photo taken 24 Sept 2005 (USGS Data Clearing House). Note pickle weed is cleared from the mud flats.

3. Hawaiian Stilt foraging and nesting sites at Nuupia WMA between 1980 and 1984.

4. Hawaiian Stilt nesting sites at Nuupia WMA between 1994 and 1996.

5. Hawaiian Stilt nesting and foraging and nesting locations at Nuupia WMA in 2006.

6. Mokapu Peninsula, located on the windward side of Oahu, is part of Marine Corps Base Kaneohe Bay and is owned and operated by the Marine Corps.

7. Nuupia Wildlife Management Area is located on the southern portion of Mokapu Peninsula. It has been a designated WMA since the mid-1960s. The WMA is composed of the ponds Nuupia Ekahi, Nuupia Elua, Nuupia Ekolu, Heleloa, Halekou, Kaluapuhi, and Paakai and their surrounding tidal mud flats.

8. DLNR Bird Count Routes. The DLNR counts waterbirds in wetland areas only. If other birds are seen in the wetlands they will record them.

9. Audubon Society Christmas Count Route. The Audubon Society conducts these counts every winter between Dec 14 and Jan 5. The Audubon Society counts all birds seen in all locations.

10. ANOVA divided into 10 year increments: 1947-1956, 1957-1966, 1967-1976, 1977-1986, 1987-1996, 1997-2005. These increments were chosen to see if there is a change in time irrespective of specific management practices. ($F(5,52) = 22.84$; $p<.0001$)

11. ANOVA Analysis 17-yr increments. Counts Divided into 3 groups:1947-1963, 1964-1981, 1982-2005. Periods chosen to differentiate two pickleweed, and mangrove removal programs, and one period after these management practices were implemented. ($F(2,55)=32.90$; $p<.0001$)

12. ANOVA Analysis pre-management period: 1947-1958, 1959-1970, 1971-1981. Periods chosen to analyze any abundance trends in pre-management period. ($F(2,32) = 3.682$; $p=0.036$)

13. ANOVA Analysis management period:1982-1988, 1989-1997, 1998-2005. Periods chosen to analyze abundance trends during specific management practices: 1982-1988 AAV ops and weed pulls; 1989-1997 AAV Ops, weed pulls, and mechanical mangrove removal; 1998-2005 AAV ops, weed pulls, and red mangroves mostly removed. ($F(2,23)=7.736$; $p =.0032$)

Table 1

Year	DLNR Winter	DLNR Summer	Audobon CC	Avg Counts	Year	DLNR Winter	DLNR Summer	Audobon CC	Avg Counts
1947			127	127	**1977**	81	67	58	69
1948			128	128	**1978**	64	93	90	82
1949			41	41	**1979**	99	115	124	113
1950			11	11	**1980**	116	50	94	87
1951			66	66	**1981**	56	70	76	67
1952			31	31	**1982**	62	38	68	56
1953			28	28	**1983**	68	9	79	52
1954			9	9	**1984**	No Data	51	69	60
1955			24	24	**1985**	66	No Data	109	88
1956			42	42	**1986**	No Data	110	97	104
1957			0	0	**1987**	92	110	143	115
1958			27	27	**1988**	154	No Data	121	138
1959			13	13	**1989**	50	162	116	109
1960			21	21	**1990**	135	No Data	116	126
1961	34		94	64	**1991**	122	No Data	99	111
1962	19		37	28	**1992**	137	86	76	100
1963	32		45	39	**1993**	No Data	No Data	121	121
1964	No Data		18	18	**1994**	No Data	No Data	No Data	No Data
1965	73		39	56	**1995**	169	152	No Data	161
1966	72		103	88	**1996**	123	NC	143	133
1967	33		52	43	**1997**	137	124	127	129
1968	74		24	49	**1998**	176	109	139	141
1969	51		39	45	**1999**	100	116	127	114
1970	10	51	36	32	**2000**	121	113	113	116
1971	33	27	72	44	**2001**	135	142	114	130
1972	36	48	54	46	**2002**	115	137	136	129
1973	80	52	58	63	**2003**	124	148	122	131
1974	No Data	65	81	73	**2004**	116	158	146	140
1975	39	56	91	62	**2005**	152	125	126	134
1976	62	89	122	91	**2006**	140	113	No Data	127

Table 2

Management Practices

Year	Mangrove Removal (acre)(1)	Pickleweed / Mangrove Propagule removal by volunteers(2)	Mud flat AAV Ops (ha)(3)	Predator Control(4)
1980				X
1981		X		X
1982		X	5	X
1983		X	5	X
1984		X	5	X
1985		X	5	X
1986		X	5	X
1987		X	5	X
1988		X	5	X
1989		X	5	X
1990		X	5	X
1991	2	X	5	X
1992		X	5	X
1993		X	5	X
1994	2	X	5	X
1995	12.5	X	5	X
1996		4	5	X
1997	3	4	5	X
1998		4	5	X
1999	5.7	4	5	X
2000		4	5	X
2001		X	5	X
2002		X	5	X
2003	3.5	X	5	X
2004		X	5	X
2005		X	5	X
2006		X	5	X
2007		X	5	X

(1)In 1982 approximately 25 acres. Removed mechanically and by hand.
(2) Volunteers remove pickleweed and red mangrove propagules by hand.
(3) Mud ops target pickleweed and young red mangrove in tidal mudflats.
(4)Detailed predator control data available for 2006 only.

Figure 1

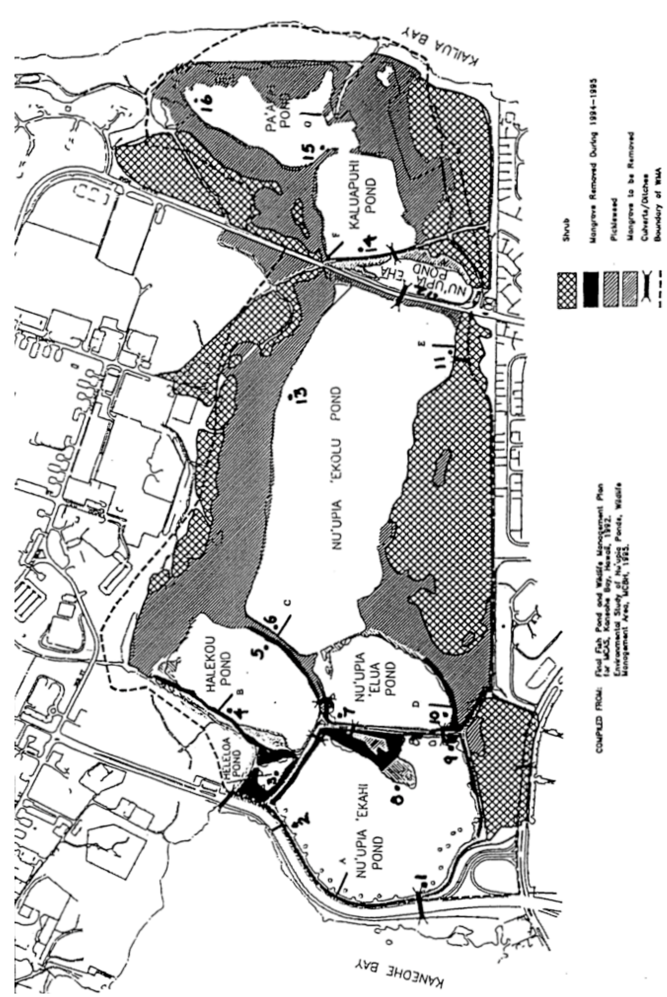


Figure 2

Figure 3

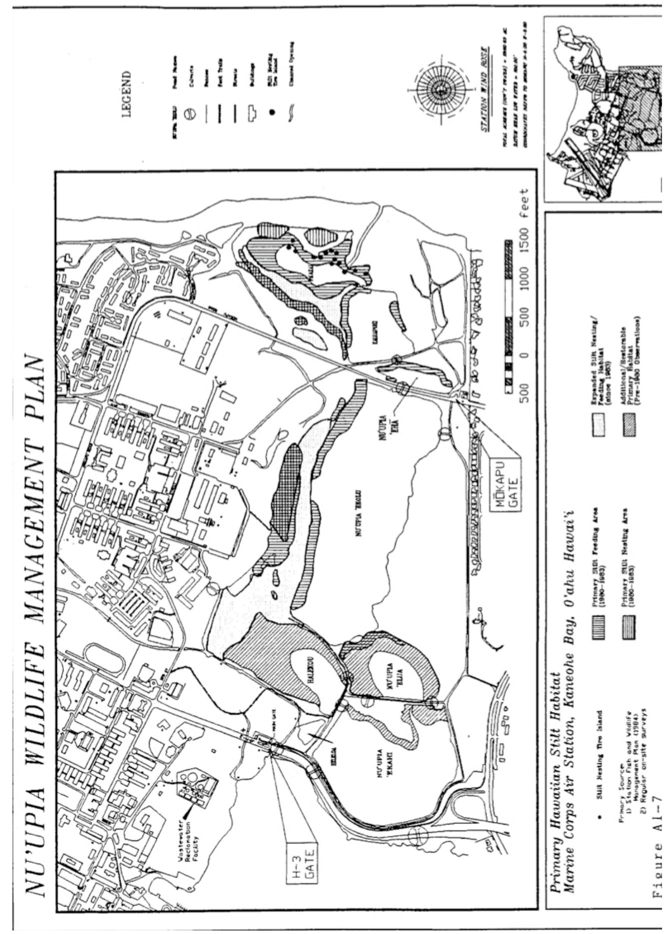


Figure 4

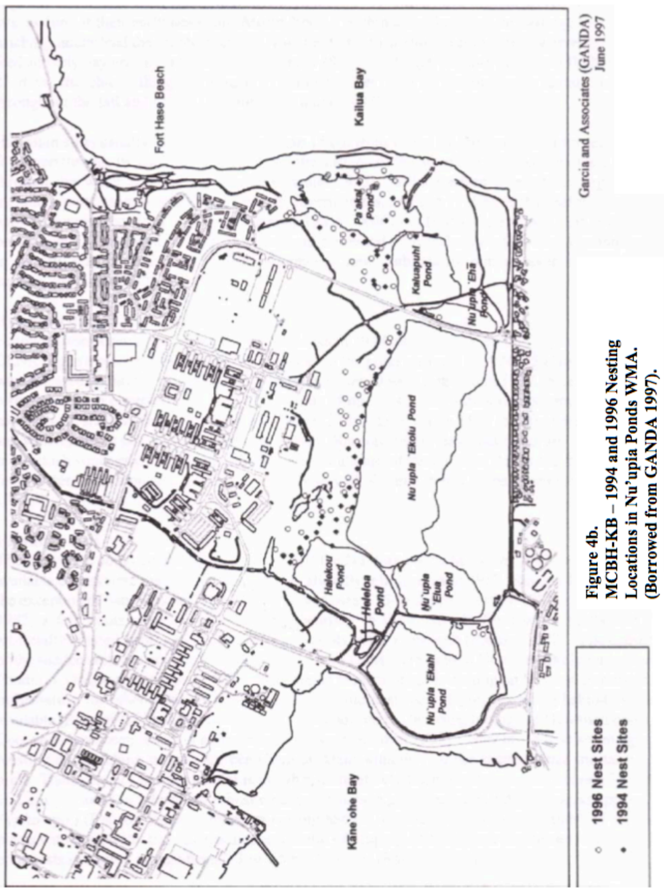
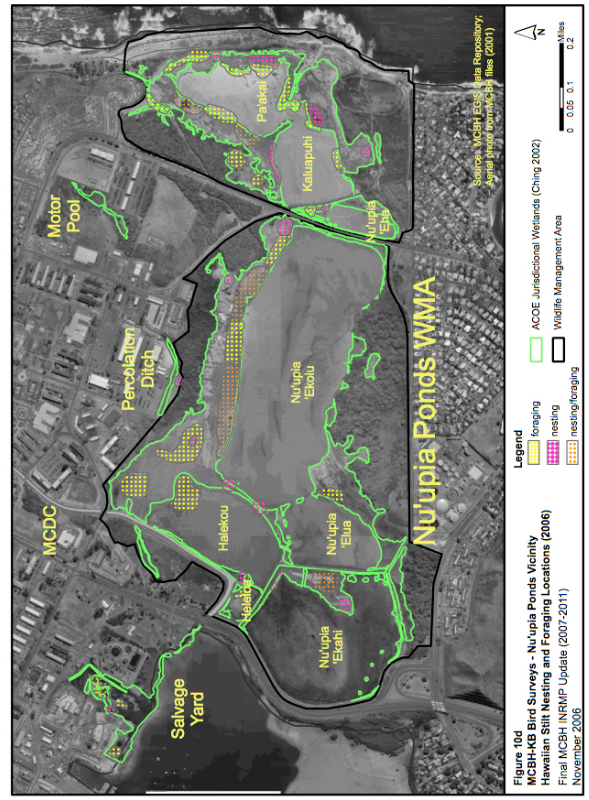


Figure 4b.
MCBH-KB – 1994 and 1996 Nesting Locations in Nu'upia Ponds WMA.
(Borrowed from GANDA 1997).

Figure 5



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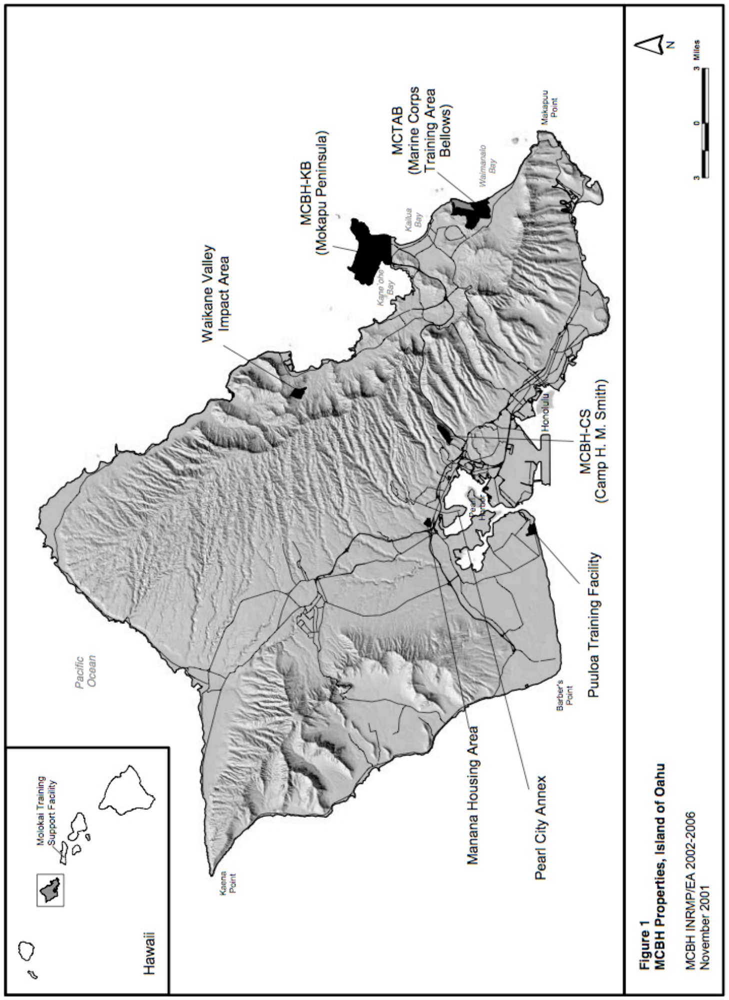


Figure 7

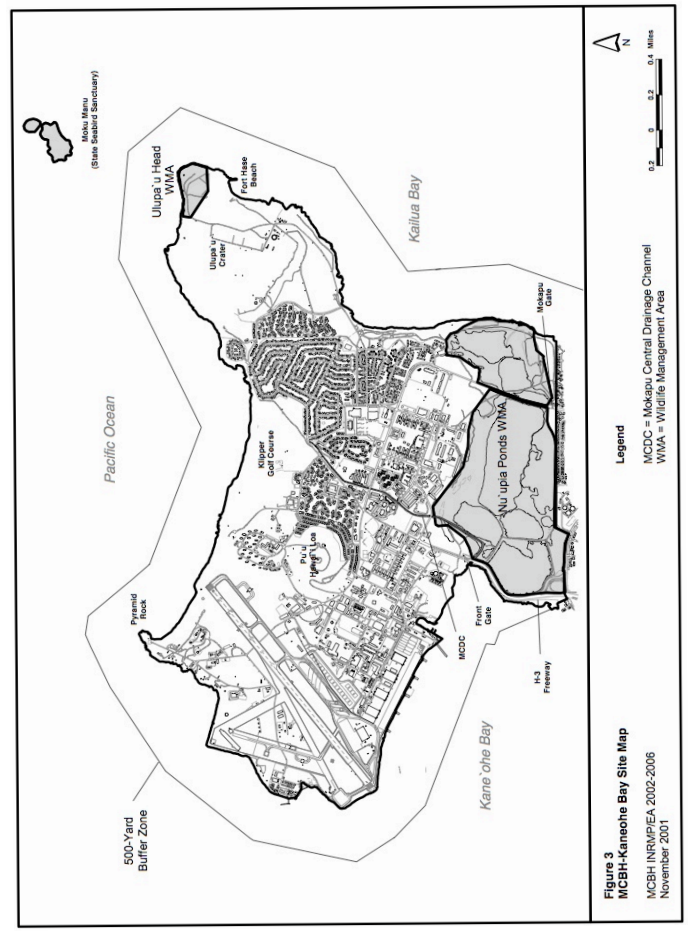
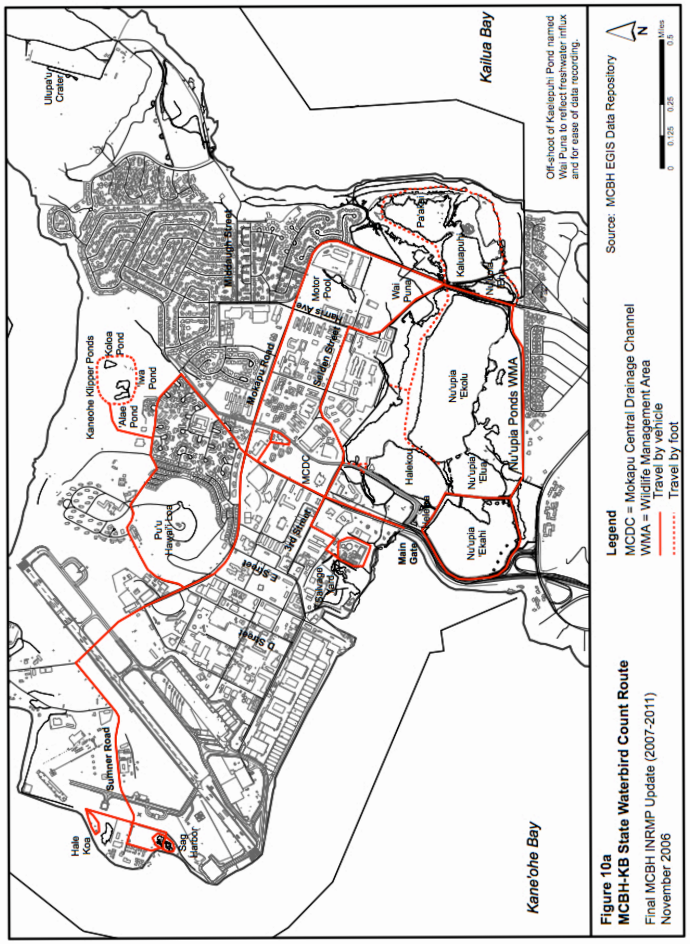


Figure 8



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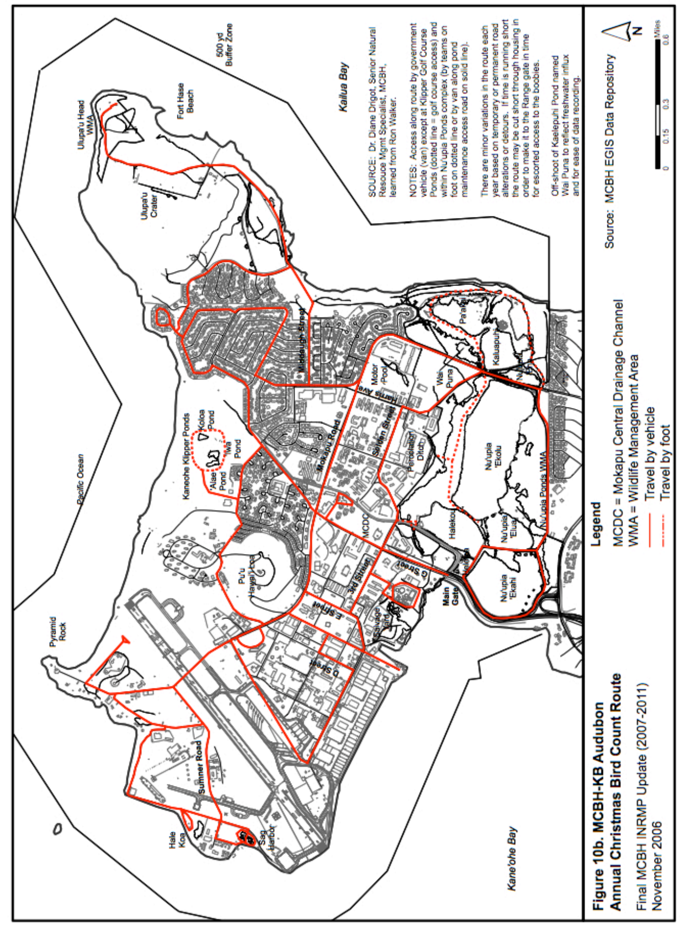
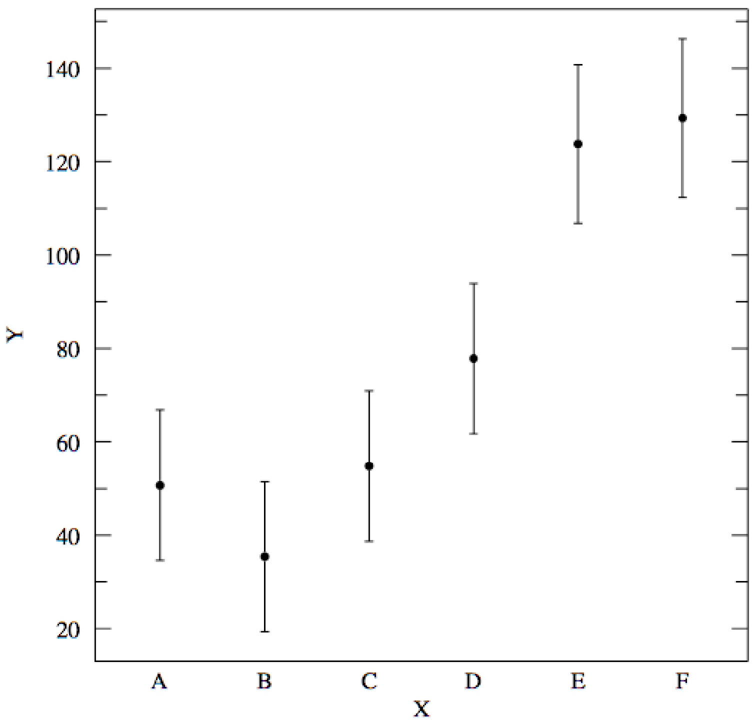


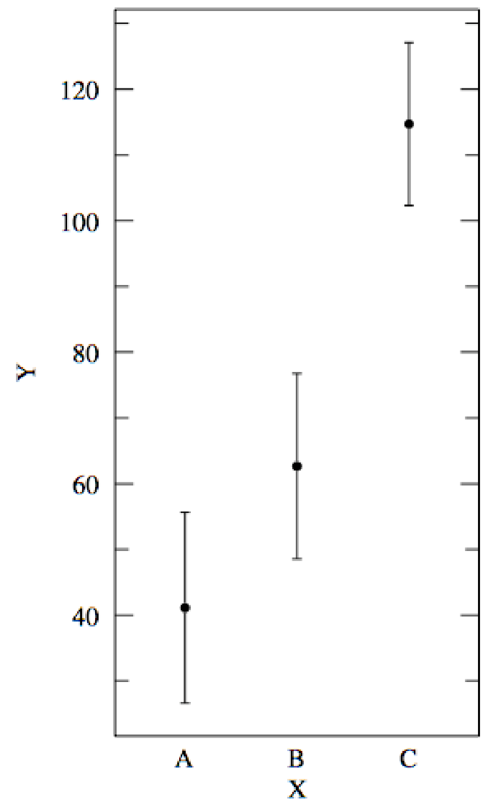
Figure 10



A = 1947-1956
B = 1957-1966
C = 1967-1976
D = 1977 – 1986
E = 1987 – 1996
F = 1997-2005

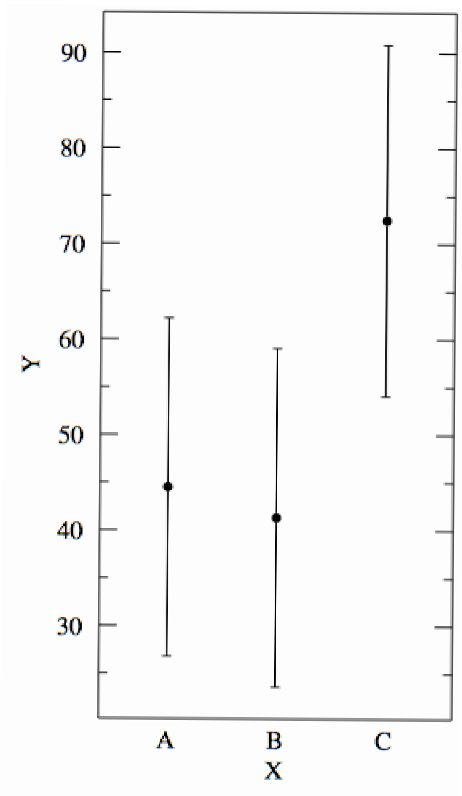
$F(5,52)=22.84$, $p<.0001$

Figure 11



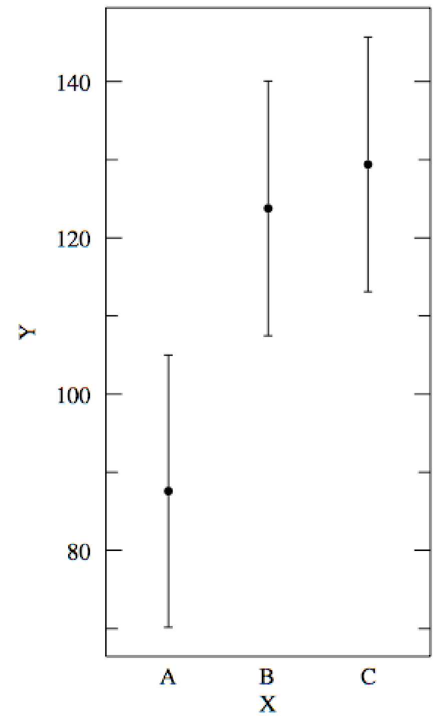
A =1947-1963
B = 1964 – 1981
C = 1982 – 2005
$F(2,55)=32.90$, $p<.0001$

Figure 12



A = 1947 - 1958
B = 1959 - 1970,
C = 1971 – 1981
F(2,33)=3.682, p=0.036

Figure 13



A = 1982-1988
B = 1989-1997
C = 1998-2005
F(2,23)=7.736, p = .0032

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