KĪHOLO FISHPOND ESTUARY:

HYDROLOGY, WATER QUALITY, FISH AND LARVAL SURVEYS TECHNICAL REPORT

Prepared for the National Oceanic and Atmospheric Administration's Coral Reef Conservation Program

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Kīholo fishpond during a high tide (August 2013), showing water spilling over the remnant rock walls and onto land.

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Rebecca Most, Chad Wiggins, Dave Ziemann

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Acknowledgements

The Nature Conservancy would like to take this opportunity to thank NOAA's Coral Reef Conservation Program and the many community members and volunteers who have supported this study and the rehabilitation of Kīholo Fishpond. We would like to thank our partners Hui Aloha Kīholo, for their support and guidance as we learn from and care for Kīholo. For their dedication while staying up all night during our 24-hour surveys, a special thank you to Ily Iglesias, Leilani Warren, Kanoe Morishige, Kathryn Bland, Linda Callery, Karen Bitan, Joshua Inaba, David Ziemann, and Kanekoa Kukea Shultz. For participating in many cold fish surveys with a smile and aloha, a warm thank you to Sandy Lehua Kamaka and Kekaulike Tomich. A special thank you to community members Bart Wilcox, Ku'ulei Keakealani, Mike Donoho, Pua'alaokalani Nihau, and Pelika Bertelmann who continue to support scientific studies, monitoring, outreach and education at Kīholo, and whose legacy of stewardship will live on for generations. Without the support and leadership of Jenny Mitchell and Ku`ulei Keakealani or the generosity of Angus Mitchell, none of this work would be possible. Finally, we would like to acknowledge Kīholo, the place that provides us with opportunities to learn, to share, and to grow.

EXECUTIVE SUMMARY

Kīholo fishpond estuary is located on the North Kona coast and owned and managed by The Nature Conservancy. In Hawaiʻi, fishpond estuaries function as a vital interface between land and coastal waters, providing habitat for native flora and fauna above and below their sheltered waters. Kīholo fishpond estuary supports populations of estuarine fish, Pacific Green Sea Turtles, and marine fish species associated with coral reef habitats. Since 2012, The Nature Conservancy has begun rehabilitation of the fishpond estuary working directly with community members and agency partners to improve ecosystem health. In addition to rehabilitation efforts to improve habitat for native plants and animals, The Nature Conservancy is monitoring the physical and biological conditions at the fishpond to document the effects of rehabilitation on fishpond water quantity and quality as well as fish abundance, biomass, and recruitment. These data are directly relevant to coastal areas and contribute valuable information to our understanding of the role and function of fishpond estuaries in Hawaiʻi. This study summarizes results from ongoing monitoring efforts in the fishpond estuary from December 2012-September 2013.

The results of this study show:

- Kīholo fishpond estuary provides habitat for over 19 species of fish, both estuarine and reef species.
- Most of the fish in Kīholo fishpond estuary are juveniles.
- Kīholo fishpond estuary is both a source and a sink for estuarine and reef fish.
- 3-5 million gallons a day of submarine groundwater flows to coastal waters through Kīholo fishpond.
- This submarine groundwater discharge is high in nutrients (nitrate, phosphate, and silicate).
- Nutrient concentrations decrease with distance from groundwater sources.
- Ammonium concentrations appear to be driven by bacterial breakdown of organic sediment, and increase in concentration towards the ocean.
- Ocean water enters the fishpond only during the rising high-high tide each tidal cycle, mixing throughout the fishpond. Water flows from the fishpond estuary to coastal waters throughout the rest of the tidal cycle.

Ongoing monitoring of the fishpond water quantity, quality, fish abundance, biomass, and recruitment will aid managers to effectively characterize the relationship between fishpond estuaries and fringing coral reefs in Hawaiʻi. Our goal at Kīholo is to gather this data along with biological data designed to develop and implement an adaptive management strategy to sustainably harvest fish in the future improving community resilience while restoring habitat and strengthening cultural connections.

INTRODUCTION

Hawaiian fishpond estuaries, such as ka loko o Kīholo (Kīholo fishpond), were managed as traditional aquaculture systems to provide sustainable seafood to Hawaiʻi's ruling class and the community in times of need. More recently, these fishpond estuarine systems provided financial benefits to landowners and managers through intensive production of commercial fish species. Today, a handful of fishponds are still producing sustainable locally-farmed seafood, while many others are being rehabilitated to return them to more ecologically, culturally, and socially favorable conditions. In 2011, ka loko o Kīholo was donated to The Nature Conservancy (TNC) to ensure it would be protected and managed.

In 2012, The Nature Conservancy worked with Hawaiʻi's State Parks Division, the Ala Kahakai National Historic Trail, local non-profit Hui Aloha Kīholo, and Conservation International representatives to facilitate a Conservation Action Plan (CAP) that outlines priority strategies to maintain or enhance the viability of Kīholo's conservation targets. The plan's scope included the 500 acre Kīholo State Park and all of Kīholo Bay, and the CAP partners agreed to focus on strategies relevant to Kīholo fishpond in the short term. Based upon the CAP's mutually agreeable strategic priorities, TNC began a project for the fishpond to improve estuarine habitat using an adapted traditional management approach with four main goals: 1) return Kīholo fishpond to its documented former ecological health by managing threats to fish habitat; 2) evaluate the connection between Kīholo fishpond and the adjacent shoreline to determine the fishpond's contribution to reliable and sustainable production; 3) improve or return coastal habitat to support formerly documented native flora and fauna; and 4) provide a place for researchers, students, and community members to study nature, learn about estuarine systems and traditional fishpond management, and innovate solutions to conservation's critical threats at multiple scales.

This study addresses the management goals listed above by quantifying the fishpond hydrology, water quality, fish population, and larval recruitment dynamics. Hydrology and water quality are being measured over tidal cycles to quantify groundwater discharge into the fishpond, and determine the physical conditions and nutrient concentrations in the fishpond. The monthly fish surveys are providing the first comprehensive assessment of adult and juvenile fisheries stocks in the fishpond; including species-level abundance and biomass. The fish surveys will help managers to assess the effects of fishpond rehabilitation on fish populations. The objective of the larval study is to determine the role of the fishpond in larval and juvenile fish production, survival and recruitment by examining larval and juvenile fish exchange between the fishpond and the Kīholo Bay coastal zone. The larval surveys provide evidence of fish and invertebrate recruitment to and from the fishpond and the seasonal cycles of larval replenishment. To help assess the roles of water exchange on larvae and juvenile fish exchange, and relationships between water quality and fish abundance and composition, water flow and water quality measurements were made during the larval fish sampling surveys. This report provides the results of the surveys from December 2012 to September 2013.

METHODS

Surveys were carried out between December 5th, 2012 and September 7th, 2013. Sampling dates for each survey type are indicated in Table 1. Water flow, water level, and larval recruitment were measured during three 24-hour survey events in April, May and August. Nutrient sampling occurred in May, and physical water quality measurements were made in May and August. Five in situ fish surveys were completed in December 2012, and April, June, July, and September 2013.

Table 1. Dates of each sampling event (shaded in grey) at Kīholo fishpond; including water flow, water level, nutrient sampling, physical hydrology measurements, fish surveys, and larval sampling.

Date	Moon phase	Surveys Completed (shaded in grey)					
		Water flow	**Water level**	**Nutrient samples**	**Physical conditions and hydrology**	**Fish survey**	**Larval samples**
December 5th, 2012	Third Qtr.						
April 2nd, 2013	Third Qtr.						
April 25-26th, 2013	Full						16 net samples (2 samples @ 8 tidal phases)
May 8-9th, 2013	New						16 net samples (2 samples @ 8 tidal phases)
May 25th, 2013	Full						6 net samples (3 @high tide, 3 @ low tide)
June 20th, 2013	Full						6 net samples (3 @high tide, 3 @ low tide)
July 22nd, 2013	Full						6 net samples (3 @high tide, 3 @ low tide)
August 20-21st, 2013	Full						16 net samples (2 samples @ 8 tidal phases)
September 7th, 2013	New						

Survey locations are shown in Figure 1. Larvae were sampled using a neuston net (250 micron mesh, dimensions of opening 0.5 x 1.0 m) at the ʻauwai (channel connecting fishpond to the ocean). Concurrent water flow measurements during larval sampling were made using a water flow meter (General Oceanics mechanical flow meter) attached to the center of the neuston net opening. Flow meters were calibrated through triplicate tows over 50m of still water prior to use. Water level data were collected in the south and north fishponds. Physical water quality measurements were made in the ʻauwai and in the channel connecting the two fishponds. Nutrients samples were collected at multiple points in both fishponds, in the ʻauwai, and in the ocean immediately adjacent to the ʻauwai.

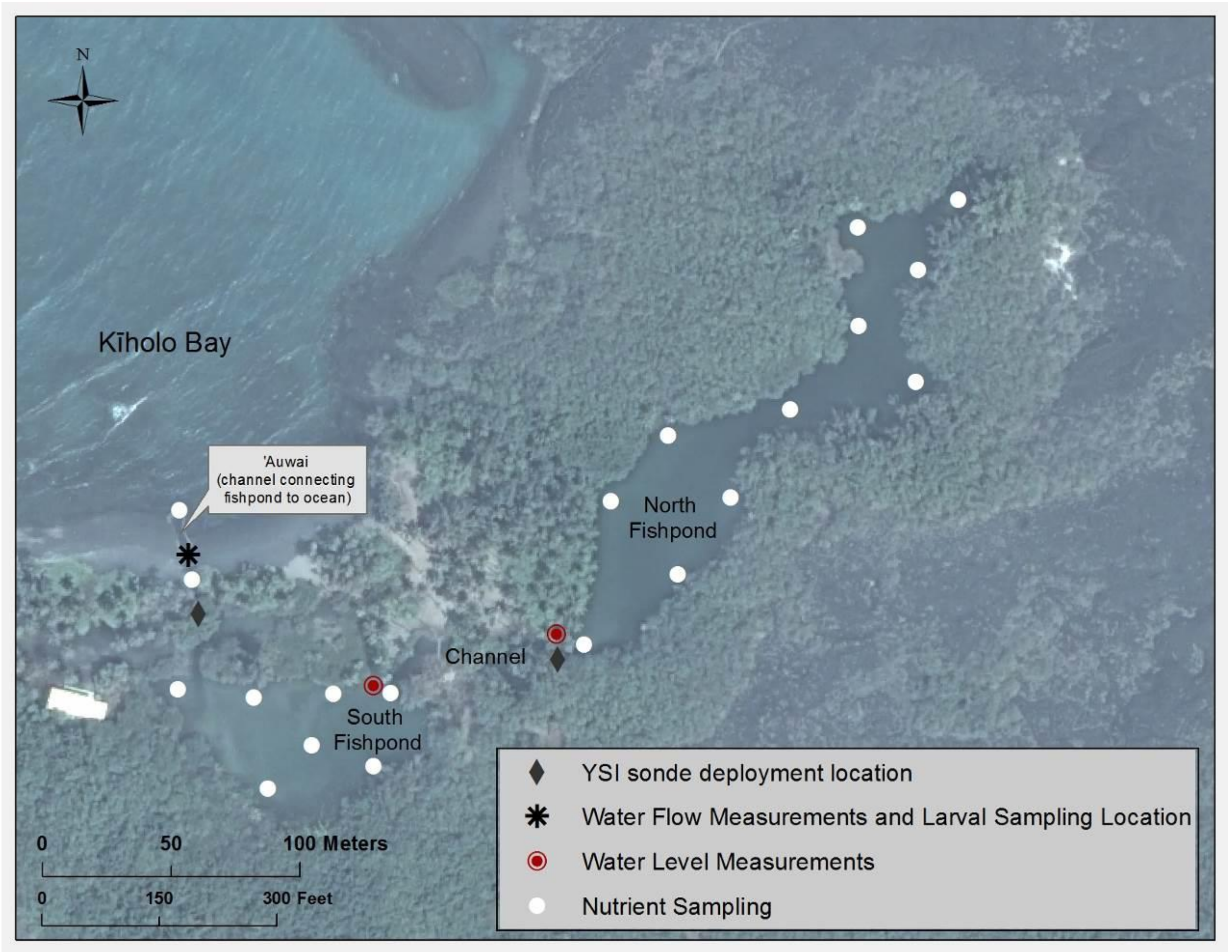

Figure 1. Aerial photo of Kīholo fishpond indicating survey sampling locations for larval net casts, YSI sonde deployments, water flow, water level, and nutrient sampling. The fishpond system consists of two wide pond areas connected to one another by a narrow channel and connected to the ocean by a rock line ʻauwai.

HYDROLOGY AND WATER QUALITY SURVEYS

A multi-parameter sonde (Yellow Springs Instruments, YSI-sonde 6920v2) was used to measure physical water quality parameters (temperature, salinity, depth, dissolved oxygen and turbidity). Two sondes were deployed for a 24-hour period (five minute sampling interval) in the fishpond ʻauwai in the channel connecting the two fishponds. A groundwater spring is located in this channel. The YSI sonde was deployed on May 8-9th and August 20-21st, 2013.

Nutrient samples were collected at 20 sites in the fishpond. High tide samples were collected at the water surface. Low tide samples were collected at the surface and near the fishpond bottom on April 25-26th, 2013. Nutrient samples were were collected in sterile 50mL conical centrifuge vials (Spectrum Scientifics), thrice rinsed in situ prior to sample collection. Benthic nutrient samples were collected with an inverted 125mL Nalgene bottle on a pole, inverted and positioned just above the substrate, then filled and capped. Nutrient samples were placed on ice immediately after collection, and frozen within 24 hours. Samples were thawed and filtered (Whatman GFF 0.25 micron filters) at the University of Hawaii at Hilo Analytical Laboratory, and analyzed using standard methods for nitrate, ammonium, silicate and phosphate concentrations (μmol/L), using a Lachat Quikchem 8500.

Fishpond water levels were measured during the three 24-hour sampling events (April 25-26th, May 8-9th, and August 20-21st, 2013). Water level was measured at in the north and south fishponds (Figure 1) using a water level gauge. Water levels in the ponds have not been surveyed relative to sea level. Instead, the pond water-level data for both survey dates were normalized by the tide height at peak high tide; at this point, flow between the ponds and ocean was minimal and the pond surface elevations were expected to be the same as the sea-surface elevation.

Volumetric flow (m^3/s) in the ʻauwai was estimated as the product of water velocity (m/s, measured with a a calibrated analog flow meter) and the cross-sectional area of the ʻauwai (m^2) at each sampling period. The ʻauwai is rectangular at the flow station, with a constant width (1.3 m) and a height that varied with the tide and flow; the cross-sectional area was calculated for each flow determination. Volumetric flow was transformed from m^3/s to millions of gallons per day (mgd) to estimate net groundwater flow out of the fishpond over a 24 hour tidal cycle.

FISH SURVEYS

Fish surveys were conducted by TNC staff and trained community volunteers from December 2012 to September 2013. The surveys were conducted using a census approach (counting everything observed in fishpond) rather than a transect approach to prevent overestimating mobile fishes. Towing Garmin GPS units in tracking mode, surveyors swam the perimeter of the pond at a slow speed (average time to complete surveys was 1.5 hours). In each team, one surveyor recorded fish along the fishpond perimeter to observe cryptic fish sheltering in the rocks along the edge of the fishpond while the other surveyed fish 10-30m from the pond edge to record all free swimming individuals (Figure 2).

Surveyors recorded the number and size of individuals of each juvenile and adult fish species along with time at least every 3 minutes throughout each survey. Visual estimates of fish total-length were made to the nearest 5cm for all species. Fish biomass was calculated using length-weight relationships ($W=a L^b$; W = Weight (kg), a and b = conversion constant, L=Length (cm)) for each species (www.fishbase.org).


Figure 2. Fish survey in Kīholo fishpond with trained community members.

LARVAL SURVEYS

Six surveys were conducted between April and August 2013. Surveys on April 24-25th, 2013 (full moon), May 8-9th, 2013 (new moon) and August 20-21, 2013 (full moon) were conducted over 24 hours, during all tidal phases; surveys in May, June and July 2013 were conducted only during rising and falling primary tide stages. During the

April and August 24-hour survey, duplicate samples of plankton (net cast for 5 minute sample interval)were taken with a neuston net (250 micron mesh, dimensions of opening 0.5 x 1.0 m) in the ‘auwai (Figure 3). During the May 25, June 20 and July 22, 2013 surveys, triplicate neuston net samples (net cast for 3 minute sample interval) were collected in the ‘auwai approximately two hours before and after the peak high tide. A water velocity meter was attached to the mouth of the neuston net (General Oceanics mechanical flow meter), and water velocity and direction was recorded for each sampling period.

After each net cast, the net was rinsed to allow all sample material to be collected. Large plant material was rinsed and removed from each sample, and the remaining sample material was placed in polyethylene sample containers and preserved with 30% isopropyl alcohol. Larval and juvenile fish and invertebrates in the samples were counted and identified to the lowest taxonomic level possible using a binocular stereo microscope (20 x magnifications, United Scope LLC).

Figure 3. Neuston net cast in `auwai for larval and juvenile fish sampling, during a rising high tide.

RESULTS

HYDROLOGY AND PHYSICAL WATER QUALITY

Water levels, volumetric flow and tidal heights from the April 2013 survey are presented in Figure 4. Tidal heights are from the 2013 Hawai'i marine tide calendar. Water inflow (from the ocean to the ponds) occurred at tidal heights approximately 30 cm above mean lower low water ("0" on the tide chart). Inflow occurred over a period of about four hours during the higher high tide, and approximately one hour during the lower high tide. During the April survey, approximately 3.8 million gallons of water flowed from the ocean into the ponds during high tides; approximately 7.8 million gallons flowed out of the ponds to the ocean during falling tide and the secondary tide. The net discharge from the ponds to the ocean was approximately 4.0 mgd.

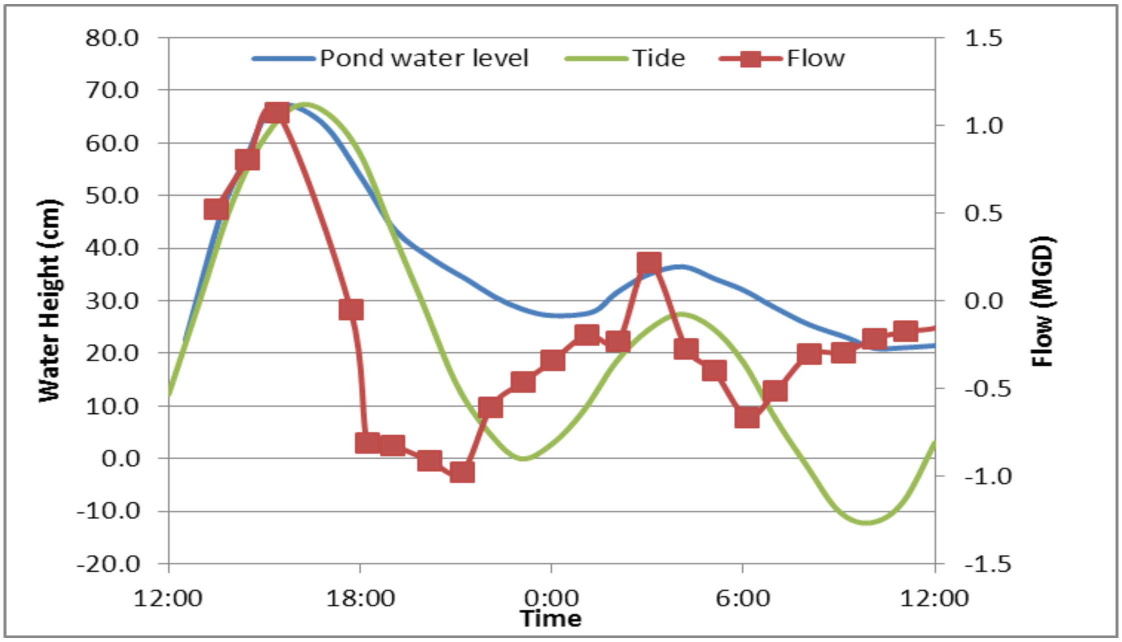

Figure 4. Tidal height (cm), pond water level (cm) and volumetric flow (million gallons/day) through the 'auwai during the 24-hour survey on April 24-25, 2013. Positive flow values indicate flow from the ocean into pond (inflow); negative values indicate flow from the pond to the ocean (outflow). Pond water levels are normalized to ocean height at peak high tide.

YSI sondes were used to measure physical water quality at five-minute intervals during the 24-hour May and August 2013 surveys. A plot of salinity vs temperature for each measurement in the 'auwai and channel connecting the two fishpond areas is presented in Figure 5. During both surveys water inflow from the ocean to the ponds occurred during the rising primary tide, when the sea surface level equaled or exceeded the level of the 'auwai. During the May inflow period, salinity increased from 17 to 26 PSU, and temperature rose from 25.5 to 28.5 ° C. During the May period of outflow, salinity decreased from 26 to 5 PSU, and temperature decreased from 29 to 23 ° C. During the secondary tidal cycle, salinity remained relatively constant at 3-5 PSU and temperature varied from 22 to 25 ° C. Similar salinity and temperature ranges were seen during the August 2013 measurements.

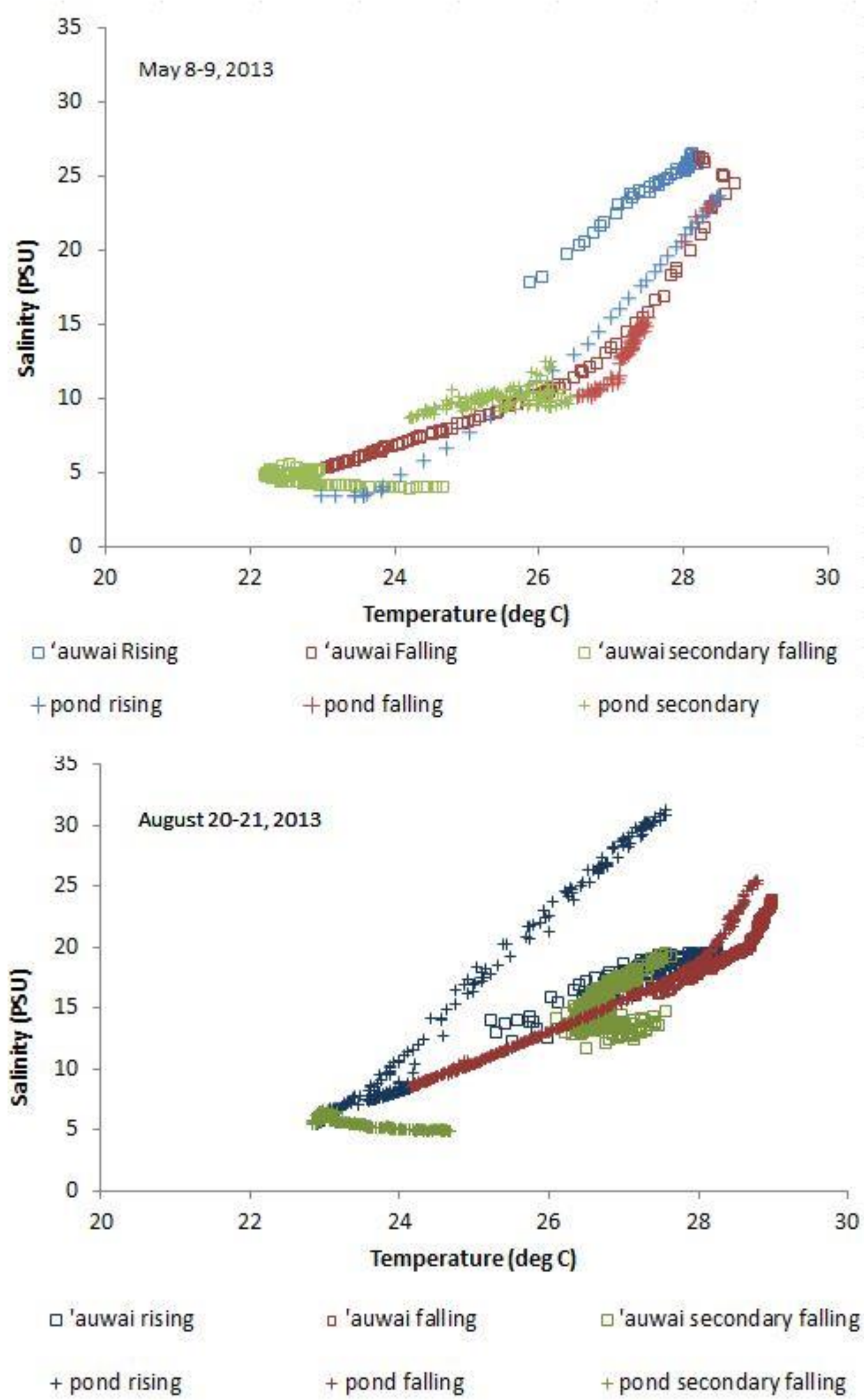

Figure 5. Variation in temperature and salinity in the ʾauwai and fishpond during a complete tidal cycle on May 8-9th, 2013 and August 20-21st, 2013.

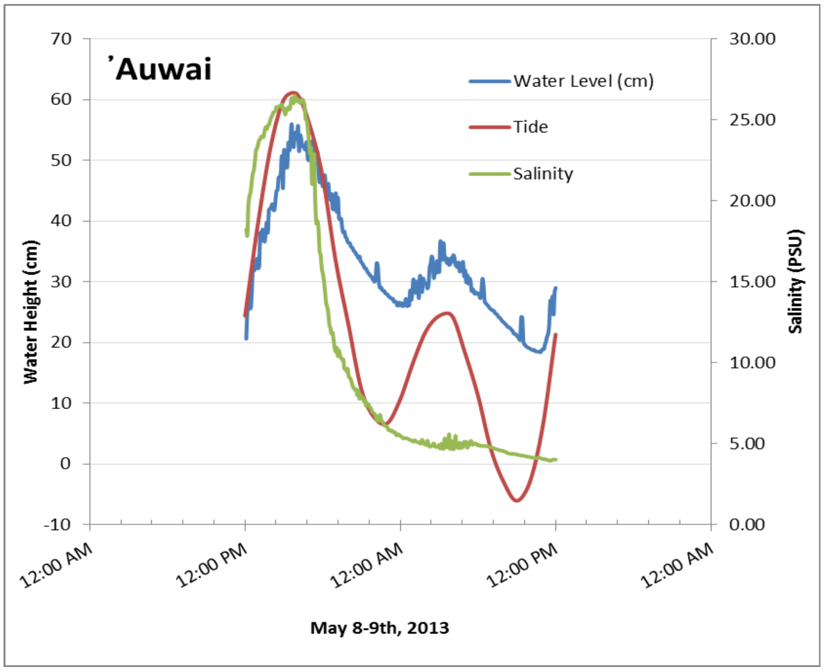

Figure 6. Water level , salinty and tidal range during the May 8-9th, 2013 survey, showing increased salinity during the rising primary high tide but not during the secondary high tide.

Figure 6 shows water level and salinity variation during the May 8-9th sonde deployment in relation to the tidal cycle. These data suggest that brackish water (3-5 PSU) discharged into the nearshore area of Kīholo Bay during lower tidal cycles is incompletely mixed with oceanic waters (typically 34-35 PSU) prior to flowing back into the fishpond at high tide. Figure 7 (University of Hawai'i – Master's Thesis by Eric Johnson, generated from surface salinity data collected in 2011) shows a brackish water plume discharged from the 'auwai traveling to the north. In this figure, salinity over most of the surface of Kīholo Bay is below 24 PSU. The T/S data in Figure 5 also show that the majority of water discharged from the fishpond is brackish water derived from a non-oceanic source. Our estimate of a net discharge of 4.0 mgd of brackish water from the fishpond and the T/S data confirm a strong source of groundwater input to the ponds.

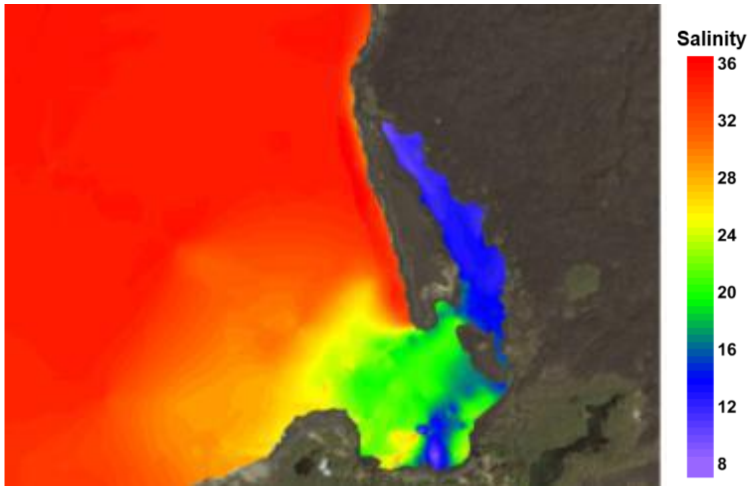

Figure 7. Surface water salinity map illustrating low-salinity plume extending into Kīholo Bay from both the northern lagoon area and the fishpond on October 23, 2011 (From E. Johnson, 2012[1]).

The bathymetry of the fishpond is characterized by broad shallow areas (less than 1 meter deep at low tide), and with the deepest areas reaching 1.5 meters at low tide. Our relative water height measurements showed a rise in water level of about 65 cm between the lowest and highest tidal stages. The ʻauwai is a relatively flat and level channel, the bottom of which is lower than the water level of the ponds at lowest tide; thus, water continuously flows from the ponds to the ocean except on rising high tide stages when the sea surface is higher than the pond surface.

A schematic diagram of bathymetry, flow direction and salinity in the Kīholo ponds during a typical spring tide cycle is shown in Figure 8. At low tide (A), pond waters are generally brackish in the upper two – three feet, with higher salinity waters in the deeper areas of the ponds. Brackish (3-5 PSU) groundwater enters the ponds at several locations along the fishpond edge and perhaps from deeper springs or seeps. This low-density water flows as a thin surface layer through the ponds and out the ʻauwai to the ocean. On the rising tide (B), once the sea level exceeds the depth of the bottom of the ʻauwai, water from Kīholo Bay flows into the ponds. Initially this water is of intermediate salinity (10-15 PSU), but as water continues to flow into the ponds, the salinity increases to levels (24 – 26 PSU) similar to surface water of Kīholo Bay. This intermediate- to relatively high-salinity water, being denser than the brackish pond water, sinks to the bottom and fills the deeper basin of the SW pond. Once this basin has been filled, this dense water flows through the channel connecting the two ponds and into the deeper basins of the larger NE pond. Water levels in the ponds rise under the influx of dense sea water, the continued influx of brackish groundwater, and to some degree in response to the general rise in the water table during rising tides.

At high tide (C), just before the tide begins to fall, flow through the ʻauwai stops. At this equilibrium point between influx and discharge, water level in the ponds is at its highest (and is the same as the water level in Kīholo Bay), and denser, higher salinity water fills the pond basins. As the tide begins to fall (D), surface water flows from the ponds to the ocean. Initially this water is relatively high salinity, but it is rapidly mixed with and finally replaced by brackish water flowing at the surface of the ponds. During the lower cycle of the diurnal tide (E), when the high tide peak is not high enough to generate flow into the ponds, the higher salinity water in the pond basins gradually

[1] E. Johnson. 2012. Surface water metabolism potential of groundwater-fed near shore waters on the leeward coast of the Island of Hawaii. M.S. Thesis. University of Hawaii at Hilo

mixes with the overlying brackish water, slowly decreasing in salinity until the next high tide phase repeats the cycle.

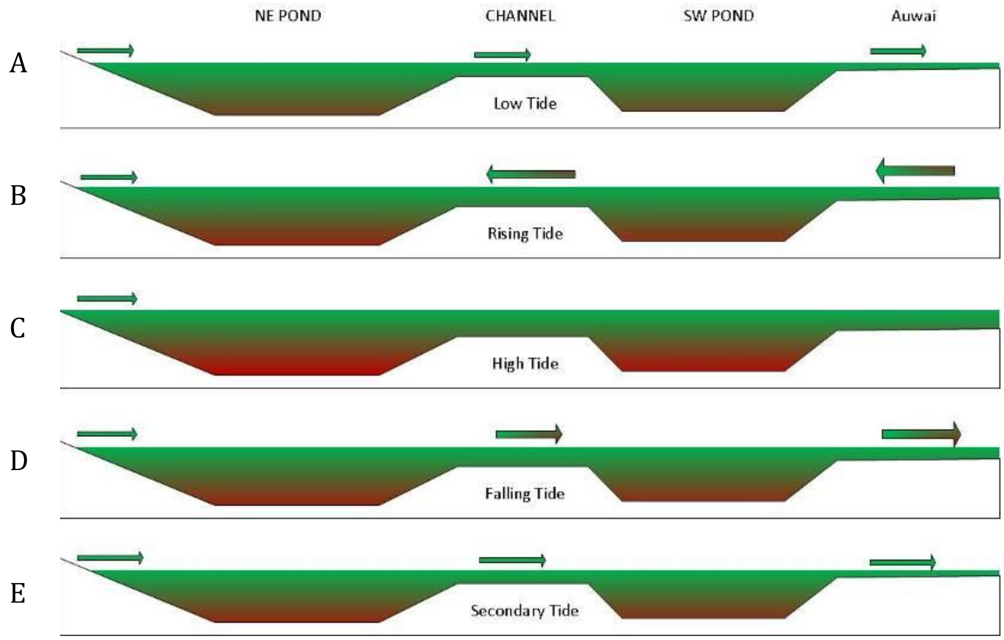

Figure 8. Schematic diagram of bathymetry, flow direction and salinity in the Kīholo ponds during a typical spring tide cycle. Brackish (3-5 PSU) waters are indicated in green, saline waters (15-25 PSU) are indicated in red and green – red gradients indicate intermediate salinity levels. See text for details.

NUTRIENT CONCENTRATIONS

Nutrient samples were collected from surface waters at high tide (n=20) on April 25th, 2013, and at low tide on April 26th, 2013 from the surface (n=20) and benthos (n=4). Table 2 shows concentrations (mean ± 1 standard deviation) for each sampling period and depth. Nitrate+nitrite, phosphate, and silicate concentrations were higher in low-tide surface samples compared to high-tide surface samples, with mid-level concentrations in benthic samples at low tide. Ammonium concentrations varied independently of the other nutrients, with highest concentrations in the surface waters at high-tide, lowest concentrations at the surface at low-tide, and mid-level concentrations at the benthos at low-tide (Table 2).

Surface-water nitrate+nitrite, phosphate, and silicate concentrations throughout the fishpond (Figure 9 and 10) generally decreased from the northeastern fishpond to the southwestern fishpond, with the lowest concentrations in the ʻauwai. In contrast to nitrate+nitrite, phosphate, and silicate concentrations, ammonium concentrations were higher in the southwestern fishpond than in the northeastern fishpond (Figure 10).

The differences between ammonium and the other nutrients in temporal and spatial patterns may be partly due to ammonium released from bacterial decomposition of organic matter in the fishpond sediments, with ammonium concentrations increasing as water moves across the sediment and flows out to the ocean at low tide, and showing a mixed pattern during high tide (Figure 10).

Table 2. Nutrient concentrations in surface water during high tide (April 25th, 2013) and in surface and benthic water during low tide (April 26th, 2013).

April 25-26th, 2013		Mean ± 1 Standard Deviation (umol/L)			
		Nitrate+Nitrite	Phosphate	Silicate	Ammonium
High Tide	Surface	29.47 ± 24.47	1.51 ±1.08	101.92 ± 11.21	4.71 ± 2.63
Low Tide	Surface	54.39 ± 6.06	2.46 ± 0.29	228.63 ± 13.94	1.95 ± 0.93
Low Tide	Benthic	32.25 ± 12.74	2.10 ± 0.27	207.25 ± 21.71	3.64 ± 0.60
Grand Total		**41.29 ± 20.87**	**2.01 ± 0.0.87**	**170.92 ± 12.71**	**3.33 ± 2.26**

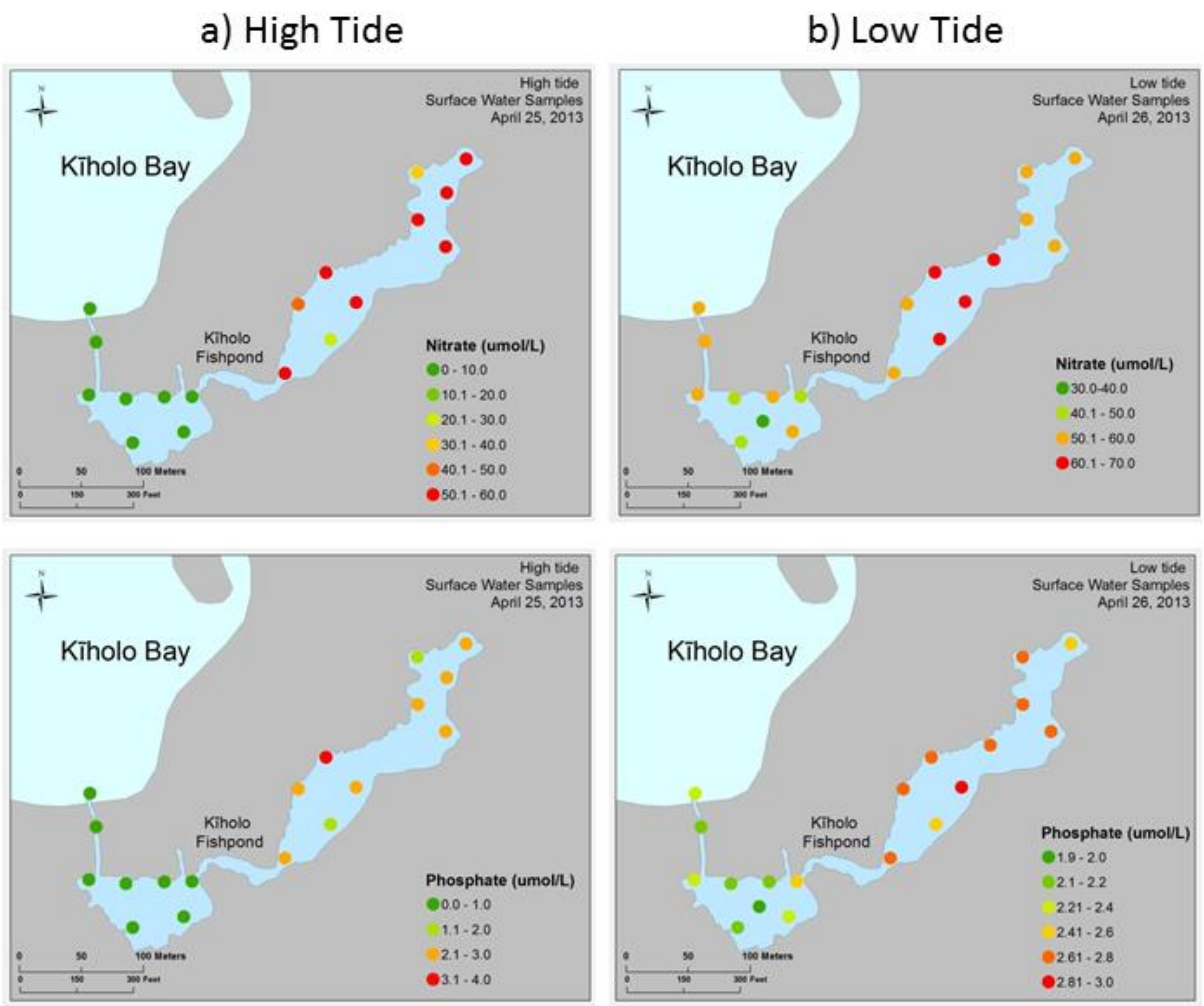

Figure 9. Distribution of nitrate+nitrite and phosphate concentrations in surface water in Kīholo fishpond surface water during a) high tide (April 25th, 2013) and b) low tide (April 26th, 2013). Note differences in legend values for different nutrients and tidal stages.

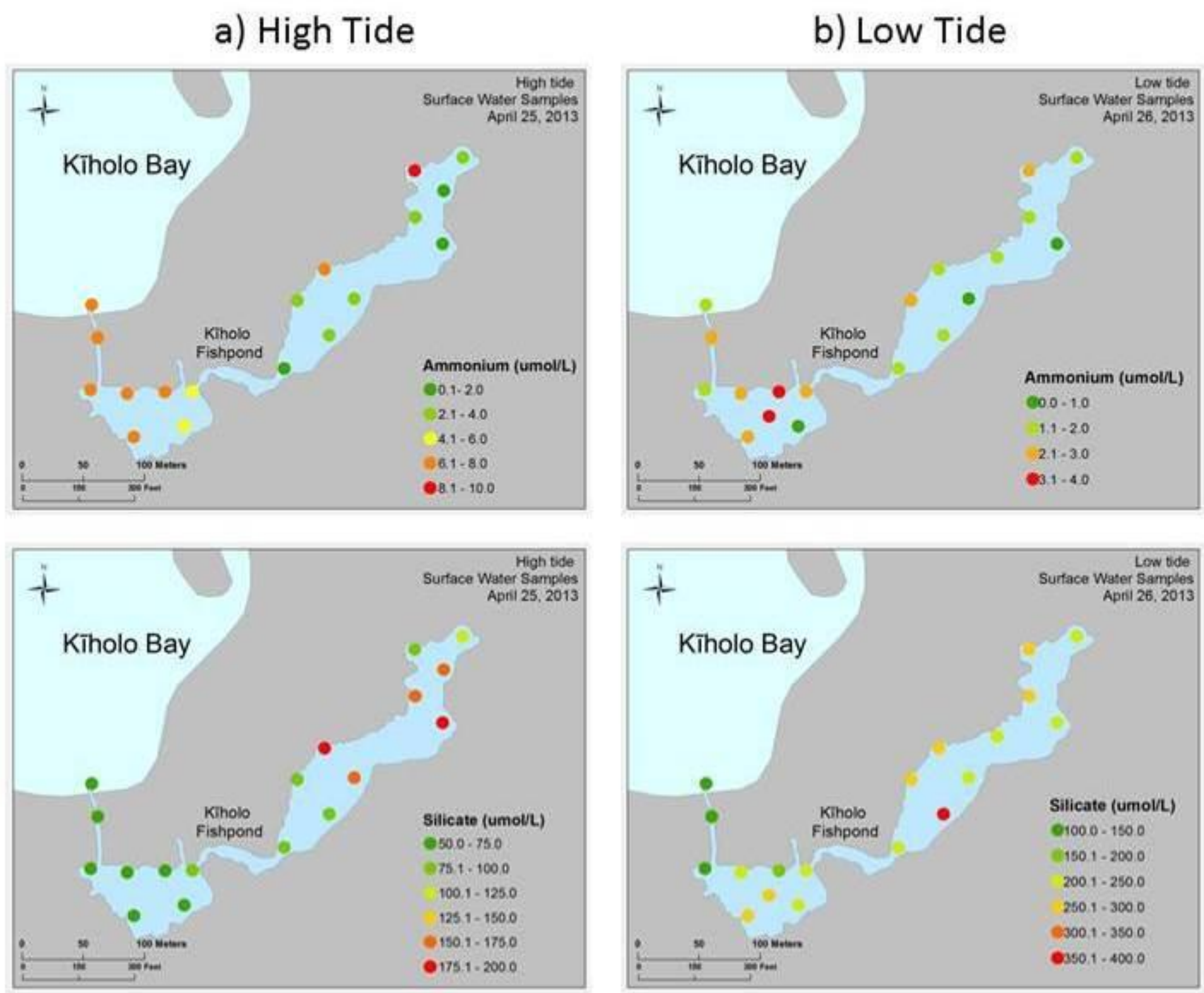

Figure 10. Distribution of ammonium and silicate concentrations in surface water in Kīholo fishpond surface water during a) high tide (April 25th, 2013) and b) low tide (April 26th, 2013). Note differences in legend values for different nutrients and tidal stages.

Fish Surveys

Fish Taxa observed at Kīholo Fishpond

A total of 20 fish taxa were observed during the surveys (Table 3). The most common species were flagtail (*Kuhlia xenura,* āholehole*)* and striped mullet (*Mugil cephalus,* ʼamaʼama), both of which were traditionally raised in fishpond estuaries by Hawaiians and are important food fish today. Repeated observations of juvenile reef fish such as Chaetodontidae during the fish surveys indicate that the fishpond functions as a nursery habitat for reef fish. The longspine porcupinefish (*Diodon holocanthus*, kōkala) has been observed frequently in the fishpond, but was not observed during the surveys. Gobies were often observed diving into the sediment during the surveys, and it is likely that their population is underestimated.

Table 3. Fish taxa observed during surveys in Kīholo fishpond from December 2012 to September 2013.

Family	Scientific Name	Common Name	Hawaiian Name
Acanthuridae	*Acanthurus triostegus*	Convict tang	manini
Atherinidae	*Atherinomorus insularum*	Hawaiian silverside	iao
Blennidae	Blennidae	Blennies	-
Carangidae	*Caranx melampygus*	Bluefin trevally	Papio
Chaetodontidae	*Chaetodon lunula*	Racoon butterflyfish	kikākapu
Chanidae	*Chanos chanos*	Milkfish	awa
Diodontidae	*Diodon holocanthus*	Longspine porcupinefish	kōkala
Gobiidae	Gobiidae	Gobies	'O'opu akupa
Kuhliidae	*Kuhlia xenura*	Flagtail	āholehole
Labridae	*Thalassoma purpureum*	Surge wrasse	hou
Lutjanidae	*Lutjanus fulvus*	Blacktail snapper	toʼau
Mugilidae	*Mugil cephalus*	Mullet	ʼamaʼama
Mullidae	*Mulloidichthys flavolineatus*	Yellowstripe goatfish	wekeʼā
Mullidae	*Mulloidichthys vanicolensis*	Yellowfin goatfish	wekeʼula
Polynemidae	*Polydactylus sexfilis*	Six-fingered threadfin	moi
Pomacentridae	*Abudefduf sordidus*	Blackspot sergeant	kūpīpī
Pomacentridae	*Abudefduf abdominalis*	Hawaiian sergeant	mamo
Pomacentridae	*Abudefduf vaigiensis*	Indo-Pacific sergeant	mamo
Sphyraenidae	*Sphyraena barracuda*	Great barracuda	kaku
Synodontidae	*Synodus spp.*	Lizardfish	ʼulae

TOTAL FISH ABUNDANCE AND BIOMASS

Total fish abundance and biomass (all taxa combined) are shown in Figure 11. The mean (±1 SD) fish abundance in Kīholo fishpond between December 2012 to September 2013 was 6,285 ± 1399. Total fish abundance (all taxa) ranged from a high of 8,723 fish in the April 2013, to 5,285 fish in the September 2013. Total fish biomass (all taxa) ranged from 572 kg in April 2013, to 1595 kg in September 2013, with a mean (±1 SD) of 1192 ± 432 kg. The simultaneous decline in biomass and increase in abundance in April 2013 can be attributed to large numbers of small *Kuhlia xenura* (<10cm) during this survey. The two most abundant fish during all surveys were *Mugil cephalus* and *Kuhlia xenura*, with average abundance of 268 ± 94 and 5,795 ± 1468 respectively, and average biomasses (kg) of 866 ± 451 and 252 ± 117 respectively (Figure 12). The abundances of less common species, including species associated with coral reefs, are shown in Figure 13.

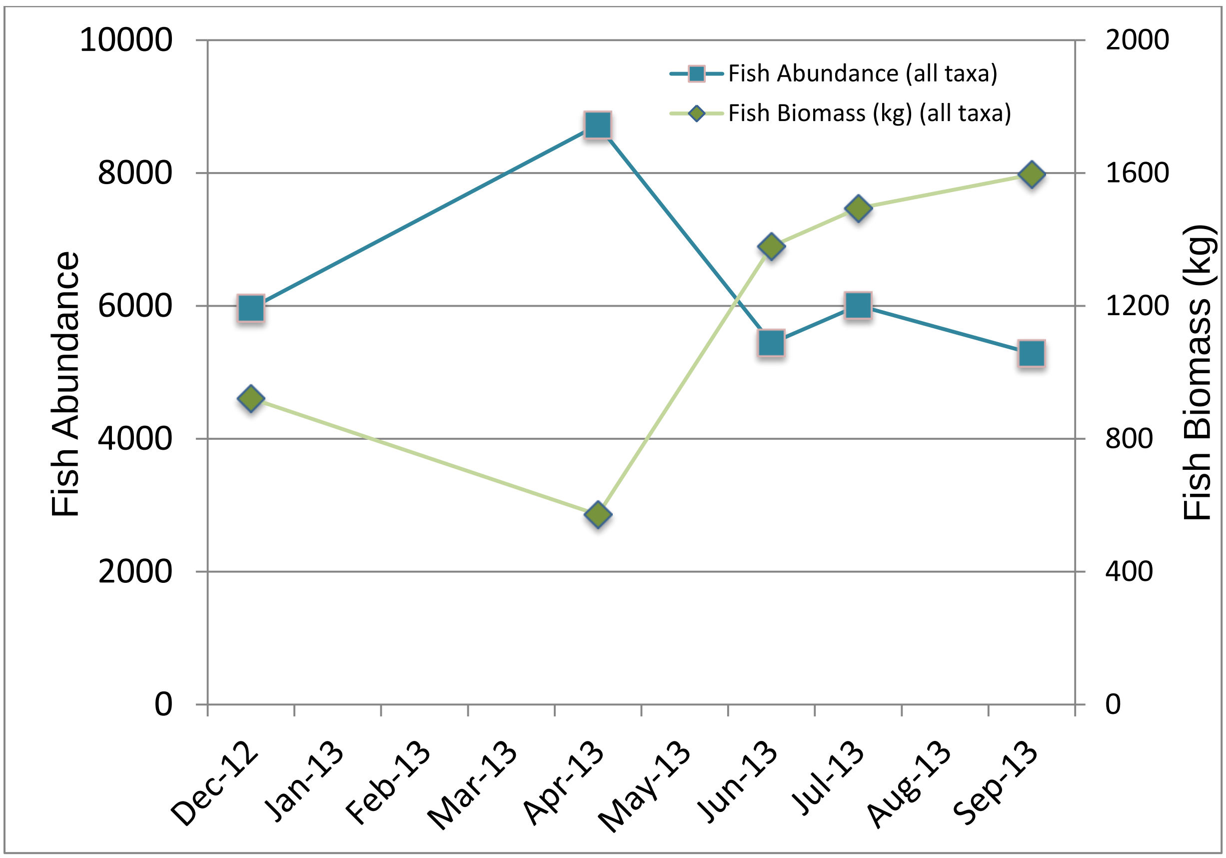

Figure 11. Fish abundance and biomass (all taxa) from December 2012 to September 2013 in Kīholo fishpond.

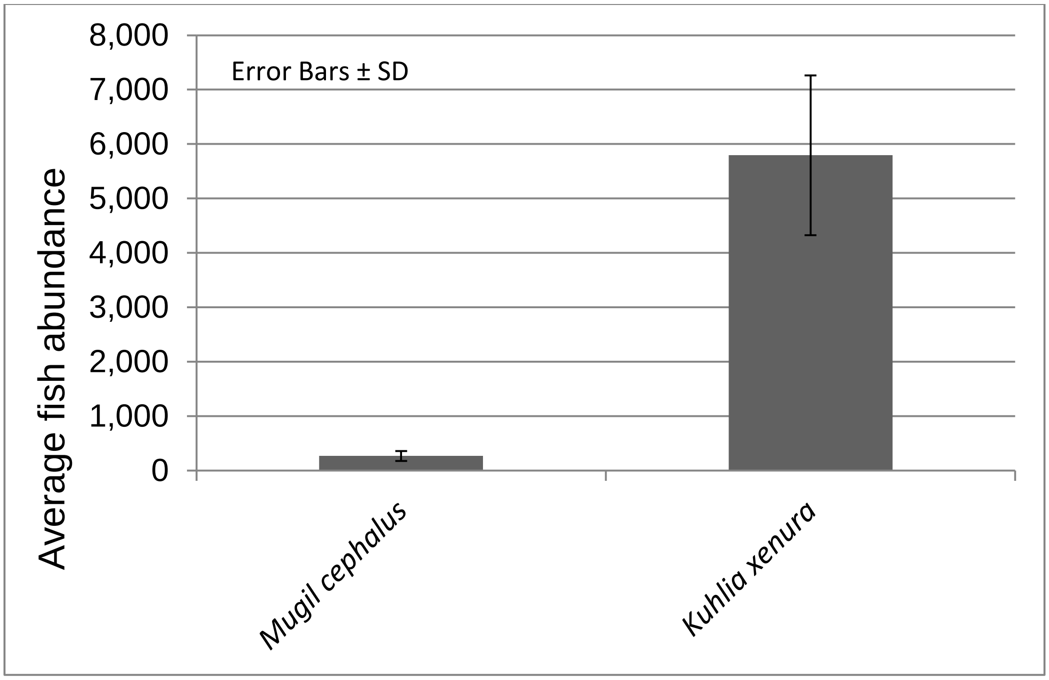

Figure 12. Average fish abundance (error bars: ±1 standard deviation) for the two most common fish in Kīholo fishpond (*Mugil cephalus* and *Kuhlia xenura*).

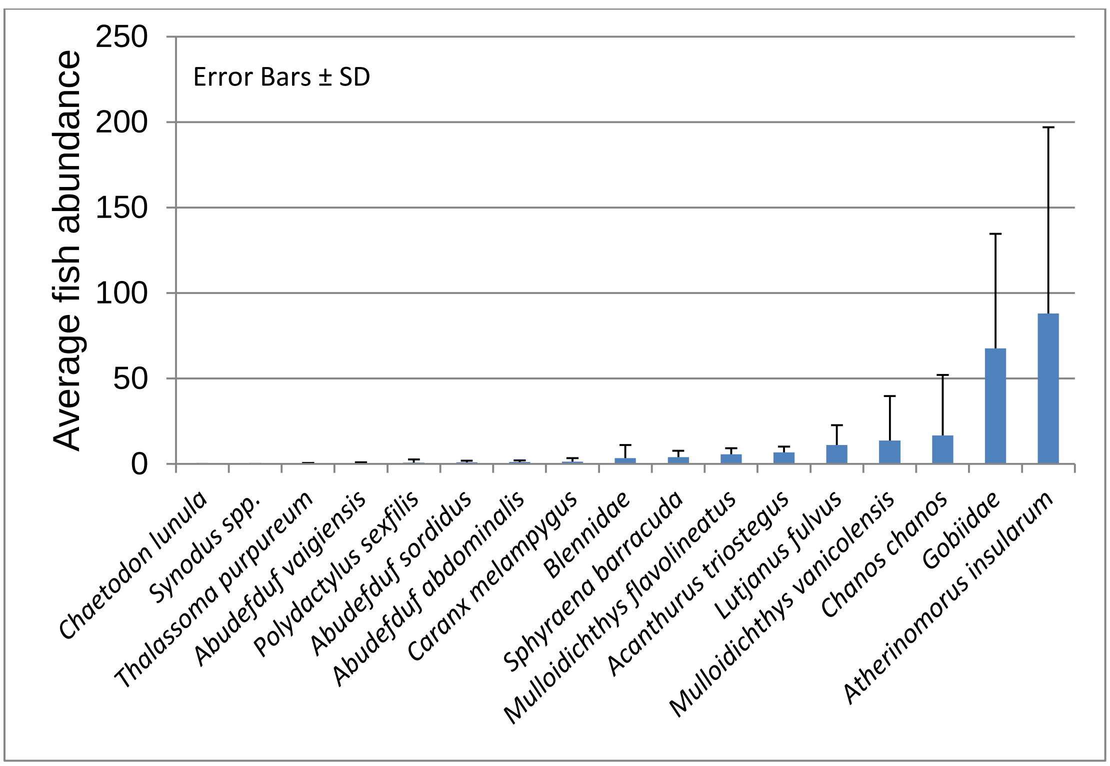

Figure13. Average fish abundance (error bars: ± 1 standard deviation) of sub-dominant fish in Kīholo fishpond.

FLAGTAIL ABUNDANCE, BIOMASS, AND SIZE

The dominant fish in the pond, in terms of abundance, was the Hawaiian flagtail (*Kuhlia xenura*, āholehole), with abundance ranging from 4696-8352, and biomass ranging from 222 - 403 kg between December 2012 and September 2013 (Figure 14). Flagtail abundance patterns were strongly skewed towards small size classes in all surveys (Figure 15). Juvenile flagtail abundance peaked in the April 2013 survey (Figure 16), which explains the low biomass and high abundance for all fish combined in Figure 11.

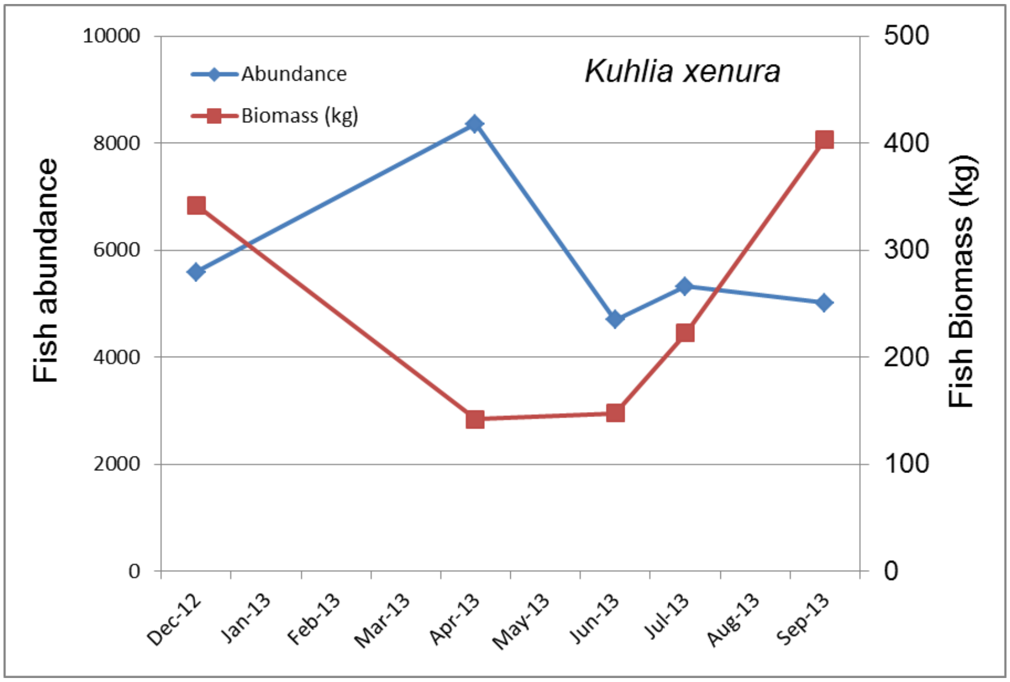

Figure 14. Total abundance and biomass (kg) of *Kuhlia xenura* during surveys from December 2012 to September 2013.

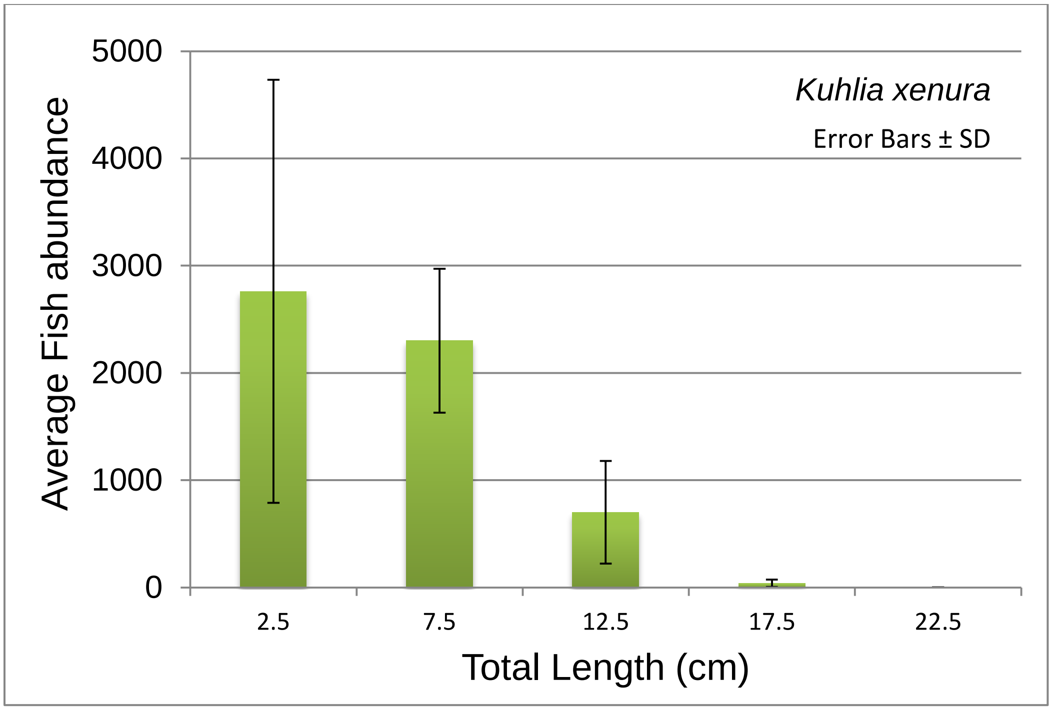

Figure 15. Average abundance (error bars: ± 1 standard deviation) of *Kuhlia xenura* by size (total length, cm).

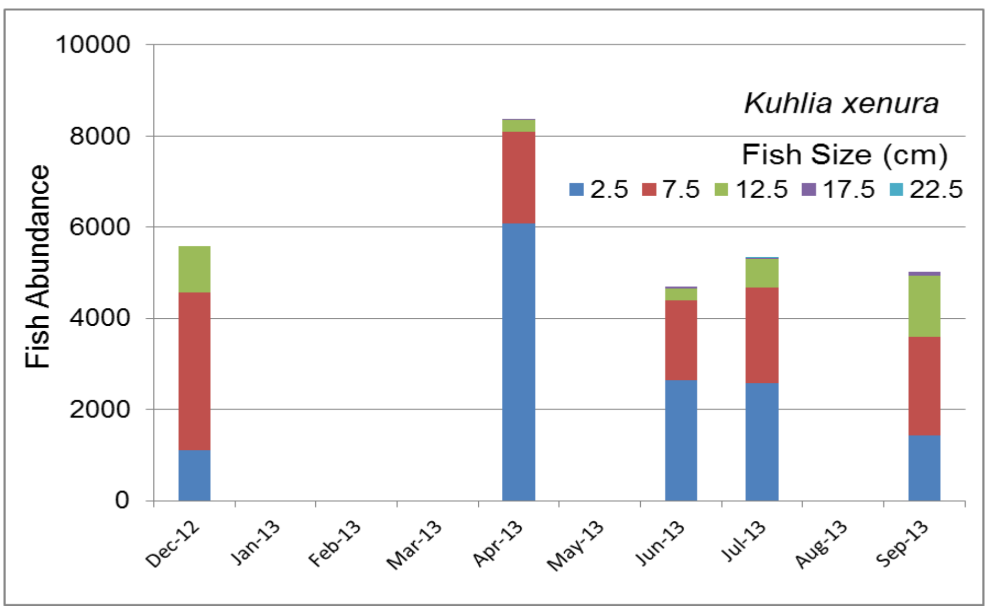

Figure 16. Total abundance of *Kuhlia xenura* by size (cm) during surveys from December 2012 to September 2013.

MULLET ABUNDANCE, BIOMASS, AND SIZE

The second most abundant fish in the Kīholo fishpond was the mullet (*Mugil cephalus*, ʻamaʻama), with abundances ranging from 142-376, and biomass levels from between 294-1296, between December 2012 and September 2013

(Figure 17). Juvenile mullet (<30 cm) were the dominant size class during all surveys, except in September 2013, when the distribution of fish numbers across size classes was relatively even (Figures 18 and 19). Increased mullet biomass during summer and fall of 2013 can be attributed to higher counts of larger mullet (>30cm) during these surveys (Figure 19) and may be indicative of seasonal movements.

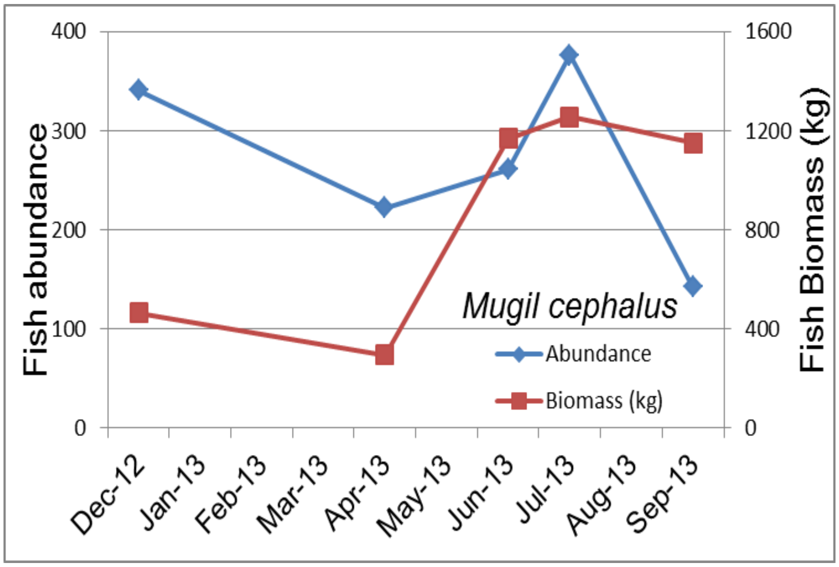

Figure 17. Total abundance and biomass (kg) of *Mugil cephalus* during surveys from December 2012 to September 2013.

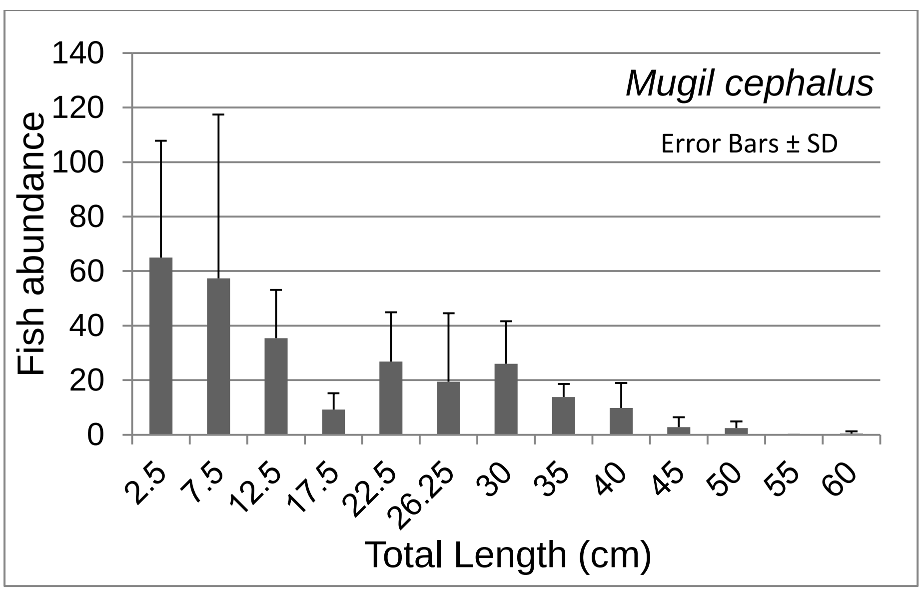

Figure 18. Average abundance (error bars ± standard deviation) of *Mugil cephalus* by size (cm).

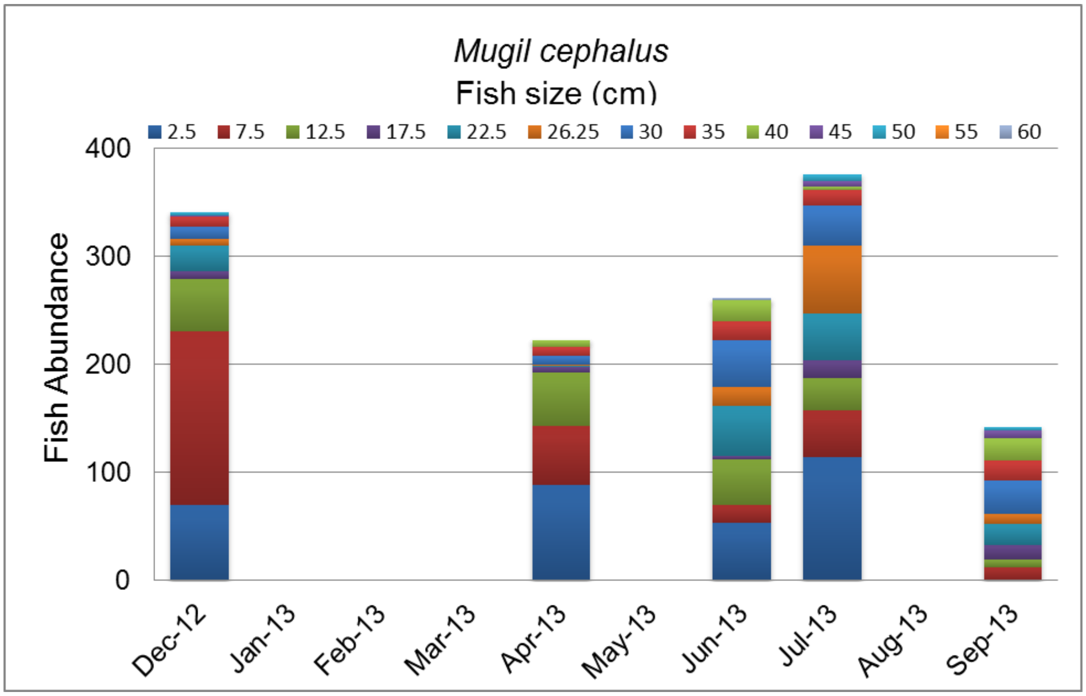

Figure 19. Total abundance of mullet (*Mugil cephalus*) by size (cm) during surveys from December 2012 to September 2013.

Reef Fish Species

Several species of reef fish have been observed utilizing the fishpond estuary. Many of the individuals observed are juveniles. These species represent diverse families including goatfish, damselfish, surgeonfish, and jacks. Reef species observed in order of abundance include: *Mulloidichthys vanicolensis, Acanthurus triostegus, Sphyraena barracuda, Caranx melampygus, Abudefduf abdominalis, Abudefduf sordidus, Abudefduf vagiensis, Synodus spp.,* and *Thallasoma purpureum*. Many of these species are resource fish, targeted by subsistence fisheries. While they do not constitute the largest abundance or biomass of fishes observed, their presence indicates the importance of the fishpond estuary as reef fish nursery habitat, and it is possible that reef fish recruitment will benefit from sediment reduction and removal strategies as the fishpond estuary's benthic habitat returns to sand and rock dominated.

Non-native Fish species

Non-native species pose a threat to harvestable stocks of desired fish species by consuming resource fish and their food sources. A non-native predatory fish that was repeatedly observed in the fishpond was the blacktail snapper (*Lutjanus fulvus*, to'au). The average abundance of the blacktail snapper was 11 individuals (SD ± 12), and ranged from 1-30 individuals during the surveys.

During the first survey in December 2012, one tilapia was observed by a trained scientific diver. Tilapia was not observed in subsequent surveys conducted by trained scientific divers and volunteers, and the December observation was assumed to be a misidentification and was not included in the analysis. However, the concern that this invasive fish could become established in the fishpond warrants careful observations and a rapid response plan if their presence in the pond is confirmed. The presence of tilapia has altered fishpond and anchialine pools systems throughout the state, and they occur in neighboring ponds at Kīholo Bay and in other Kona Coast ponds.

LARVAL SURVEYS

The results of counts of organisms from neuston net samples collected between April and August 2013 are presented in Table 4 (larval and juvenile fish) and Table 5 (crustaceans). A total of 39 larval fish and 31 juvenile fish were collected. Larval fish were most abundant in the April and May 2013 samples; 11 larval fish were collected during the April 24-hour sampling, and 13 larval fish collected in May 2013 rising-falling tidal sampling. Larval and juvenile fish were observed during in-flow and out-flow throughout the April-August 2013 sampling events, with higher counts of larval and juvenile fish found during in-flow sampling (Table 6).

During the April 2013 24-hour sampling, crab and shrimp larvae were abundant. On each 24-hour sampling event, most of the crab larvae collected were in samples from falling tides after the high high tide, and most of the shrimp larvae were in samples from rising tides throughout the sampling period. Appendix C shows total counts for larval and juvenile fish, and larval shrimp and crabs for each net cast during each sampling event.

Table 4. Results of neuston net collections for larval and juvenile fish in the ʾauwai at Kīholo fishpond between April and August 2013, for 24-hour sampling and rising and falling tide sampling. Values are the total number of fish caught on each date, the average number of fish per cast, and the standard deviation (SD) of fish per cast.

			Larval Fish			Juvenile Fish		
Neuston Net Sampling	**Month**	**Number of net casts (n)**	**Total**	**Average**	**SD**	**Total**	**Average**	**SD**
24-hour study	April	16	11	0.7	1.3	1	0.1	0.3
24-hour study	May	14	1	0.1	0.3	1	0.1	0.3
24-hour study	August	20	8	0.4	1.6	0	0.0	0.0
Rising-Falling Tide study	May	6	13	2.2	2.6	2	0.3	0.8
Rising-Falling Tide study	June	6	5	0.8	1.3	24	4.0	5.6
Rising-Falling Tide study	July	6	1	0.2	0.4	3	0.5	1.2
Grand Total		**68**	**39**	**0.6**	**1.4**	**31**	**0.5**	**2.0**

Table 5. Results of neuston net collections for shrimp and crabs in the ʾauwai at Kīholo fishpond between April and August 2013, for the 24-hour sampling and rising and falling tide sampling. . Values are the total number of shrimp and crabs caught on each date, the average number per cast, and the standard deviation (SD) of shrimp and crabs per cast.
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			Shrimp			Crabs		
Neuston Net Sampling	**Month**	**Number of net casts (n)**	**Total**	**Average**	**SD**	**Total**	**Average**	**SD**
24-hour study	April	16	952	59.5	140.4	11509	719.3	1819.3
24-hour study	May	14	40	2.9	6.9	1531	109.4	278.6
24-hour study	August	20	41	2.1	6.4	5	0.3	0.9
Rising-Falling Tide study	May	6	361	60.2	68.3	30	5.0	6.1
Rising-Falling Tide study	June	6	575	95.8	105.6	9	1.5	2.3
Rising-Falling Tide study	July	6	307	51.2	58.8	0	0.0	0.0
Grand Total		**68**	**2276**	**33.5**	**83.5**	**13084**	**192.4**	**919.0**

Table 6. Results from neuston net collections for larval and juvenile fish in the ʾauwai at Kīholo fishpond between April and August 2013, for the 24-hour sampling and rising and falling tide sampling, in relation to flow direction and rate.

Neuston Net Sampling	Moon Phase	Flow Direction	Date	Mean Larval Fish	SD Larval Fish	Mean Juvenile Fish	SD Juvenile Fish	Mean Flow Rate
24-hour study	Full	In-flow	4/1/13	1.0	1.4	0.0	0.0	-27
		In-flow	8/1/13	1.2	2.9	0.0	0.0	-17
		In-flow Total		**1.1**	**2.3**	**0.0**	**0.0**	**-21**
		Out-flow	4/1/13	0.6	1.2	0.1	0.3	24
		Out-flow	8/1/13	0.1	0.3	0.0	0.0	16
		Out-flow Total		**0.3**	**0.9**	**0.0**	**0.2**	**20**
	New	In-flow	5/1/13	0.3	0.5	0.0	0.0	-10
		In Total		0.3	0.5	0.0	0.0	-10
		Out-flow	5/1/13	0.0	0.0	0.1	0.3	25
		Out Total		**0.0**	**0.0**	**0.1**	**0.3**	**25**
Rising-Falling Tide study	Full	In-flow	5/1/13	4.0	2.6	0.7	1.2	-63
		In-flow	6/1/13	1.7	1.5	8.0	5.6	-28
		In-flow	7/1/13	0.3	0.6	1.0	1.7	-21
		In Total		**2.0**	**2.2**	**3.2**	**4.7**	**-37**
		Out-flow	5/1/13	0.3	0.6	0.0	0.0	8
		Out-flow	6/1/13	0.0	0.0	0.0	0.0	36
		Out-flow	7/1/13	0.0	0.0	0.0	0.0	24
		Out Total		**0.1**	**0.3**	**0.0**	**0.0**	**23**

Of the 39 larval fish collected, 13 were mullet (*Mugil cephalus*) ranging from 6-11mm in total length (Figure 20), 12 were Hawaiian silverside (*Atherinomorus insularum*) ranging from 11-16mm in total length, and one was an 11-mm blenny (Blennidae). Larval mullet and Hawaiian silverside were found in all sampling events between April and August 2013, with no peak larval recruitment observed. The remaining 13 larval fish samples were unidentifiable due to small size (<5mm) or collection damage. Of the 31 juvenile fish collected, 30 were mullet (*Mugil cephalus*) ranging from 23-94 mm in total length, and one was an 11-mm Longspine porcupinefish (*Diodon holocanthus)*. Flagtail (*Kuhlia xenura*), was not observed in any larval or juvenile net samples from the ʾauwai, although they are the most abundant fish in the fishpond.

Figure 20. Larval mullet and larval shrimp from neuston net samples of ʾauwai at Kīholo fishpond.

Discussion

Hydrology and Water Quality

Understanding the patterns of water flow into and out of the fishpond and the distribution of fresh and brackish water within the ponds is vital to understanding the dynamics of the pond biological communities, and the role the fishpond plays in the coastal ecosystem. Based on the water flow and water level measurement, we estimate that four million gallons of groundwater enters the pond each day, and moves into Kīholo Bay through tidal exchange. Water flow is generally outward, except for a few hours on rising high-high tides, where water flows from the bay into the fishpond. The water entering and exiting the fishpond is brackish, with variable mixing, creating estuarine conditions in the fishpond and inner Kīholo bay. The generally clear surface waters of the result from relatively shallow bathymetry and the short residence time of large volumes of groundwater flowing directly through the fishpond to the ocean. In the deeper portions of the fishpond, where water is denser and residence times are longer, cloudy, greenish tinted waters have been observed, indicating phytoplankton growth.

Inorganic nutrients play an important role in driving primary productivity rates in fishponds. The water quality assessment during high and low tides (April 2013) indicated that the groundwater input to the pond has elevated nitrate+nitrite, phosphate and silicate concentrations. Concentrations of these nutrients were highest in the north-western fishpond, and lowest at the ʾauwai. This spatial gradient is indicative of a groundwater source at the end of the pond distal to the ocean, and tidal dilution through the ʾauwai. The concentration of ammonium in the fishpond shows a reversal of this gradient, with higher ammonium concentrations in the south-eastern fishpond and near the ʾauwai, which may reflect ammonium generation in the fishpond due to decomposing organic material.

Fishpond restoration activities are expected reduce sediment accumulation by eliminating the source of organic material (leaf litter from invasive plants bordering the pond) that is generating organic sediment. Future permitted sediment removal work will be accompanied by additional nutrient monitoring, to assess the effects of restoration on nutrient concentrations and spatial patterns of sediment flux.

Additional studies of fishpond water quality and hydrology are needed for three general reasons: 1) to identify relationships between fish and invertebrate assemblages and physical and chemical conditions; 2) to assess responses of fishpond ecosystems to hydrological, oceanographic and climatic drivers; 3) to contribute to a baseline dataset for a fishpond that can serve as a sentinel site for other groundwater influenced fishpond estuaries in Hawaiʻi.

FISH AND LARVAL SURVEYS

The fish found during the fishpond surveys are both estuarine and marine. While estuarine species are most abundant, there have been continued observations of new juvenile reef species in the fishpond. The surveys showed that the fishpond is nursery habitat for some reef fish, particularly important fisheries species, highlighting the importance of fishponds for recruitment and growth for those species.

The size distribution of the common species in the fishpond, flagtail and mullet, show that the majority of fish have not reached reproductive maturity. Historically and traditionally, the fishpond had a sluice gate (mākāhā) that allowed juvenile fish to enter the pond, but prevented adult fish from exiting. The current scarcity of adult fish in the fishpond is may be due to the absence of any mākāhā and unsuccessful management of wild fish stocks in public waters. Poaching may have occurred prior to 2013 as well. In order to truly realize fisheries benefits from a managed fishpond estuary, a modified mākāhā may be needed to enhance fisheries species for an adaptive management plan for sustainable harvest, to protect breeding populations of estuarine fish from overexploitation. However, planning to design and install such a gate will need to include multiple state and federal agencies, should adult fish populations demonstrate slow or no recovery otherwise.

In the April 2013 survey the flagtail abundance increased and biomass decreased compared with the previous survey. In subsequent surveys, flagtail abundance gradually decreased and biomass increased, possibly due to losses to predation and growth of the remaining flagtail. Although their association with groundwater is documented, spawning behavior for flagtail is currently not well understood. Interestingly, no larval flagtail occurred in the neuston net samples. However, the pulse of juvenile flagtail in the pond was observed during the first month of larval sampling, and larval flagtail recruitment may have been missed, or the dynamics for flagtail may be less reliant on a pelagic larval stage and therefore completely dependent upon a functioning fishpond estuary. Since recruitment patterns show high variability in natural systems, future monitoring will determine whether or not patterns of juvenile recruitment in the spring remain consistent with this fisheries species. Continued larval sampling will be necessary to determine temporal patterns of flagtail spawning and larval recruitment and to refine our understanding for all other species sampled. Additionally, life history work on flagtail could improve our understanding of the reproductive biology of this species and is desirable.

Traditional management of the fishpond focused mullet, moi and milkfish rearing. The current presence of mullet in the fishpond suggests that physical conditions are suitable for survival. The size at reproductive maturity for mullet is approximately 30 cm, and the survey data indicate that 90% of the mullet in the fishpond are <30 cm, and therefore unlikely to reproduce. Although fisheries targets have not been set, it is desirable to have a larger abundance of reproductively mature mullet inside the fishpond estuary, if for no other reason than that this habitat is currently closed to fishing and can function as a marine reserve that confers benefits to the coastal system through larval dispersal. We intend to test this assumption rigorously by comparing changes in larval mullet abundance to reproductive mullet population dynamics. Results from neuston net samples indicated that juvenile and larval mullet moved in and out of the fishpond. Juvenile and larval mullet were collected in both incoming and outgoing tides, with higher counts during incoming tides. Larval fish sampling did not exhibit a peak larval fish recruitment period, potentially indicating multiple spawning cycles throughout the sampling period or potential for recruitment to occur outside of peak monthly tidal events. Future larval sampling should look at increasing the number of 24-hour sampling events and explore different moon phases to capture any peaks in recruitment patterns of larval fish that may have been missed during this study.

Management Recommendations

Continued monitoring of hydrology, water quality, fish population dynamics, and larval recruitment is essential to understand if rehabilitation efforts are having the desired effect on fish habitat and populations. Students and community members can participate in data collection designed to answer management questions. Information gathered from continued monitoring of the biological and hydrological dynamics of the fishpond can guide managers to develop an adaptive traditional management plan for sustainable harvest in the fishpond. Future management and monitoring recommendations based on observations from these surveys include 1) reduction of non-native predatory fish and invertebrate species 2) continued monthly monitoring of the fish population and larval recruitment 3) rapid response if the invasive tilapia is observed 4) continued and enhanced water quality monitoring to assess changes to nutrient concentrations as restoration work progresses 5) continued hydrology monitoring to characterize the physical environment in the fishpond and assess changes in groundwater inflow under different climatic and oceanographic conditions.

Appendix A. Nutrient concentrations at Kīholo fishpond (May 8-9th 2013)

Date	Tide	Depth	Sample Area	Station	Lat	Lon	Nitrate +Nitrite (µmol/L)	Phosphate (µmol/L)	Silicate (µmol/L)	Ammonium (µmol/L)
4/25/2013	High	Surface	Ocean	1	19.855243	-155.921625	2.55	0.28	57.0	7.88
4/25/2013	High	Surface	Auwai	2	19.855016	-155.921581	2.33	0.27	60.0	7.38
4/25/2013	High	Surface	Pond	3	19.854655	-155.921632	3.86	0.51	56.8	7.41
4/25/2013	High	Surface	Pond	4	19.854627	-155.921366	4.61	0.45	58.0	6.03
4/25/2013	High	Surface	Pond	5	19.85433	-155.921316	5.59	0.51	63.8	6.53
4/25/2013	High	Surface	Pond	7	19.85464	-155.921087	5.76	0.50	70.3	6.56
4/25/2013	High	Surface	Pond	8	19.854402	-155.920946	6.17	0.46	72.1	5.89
4/25/2013	High	Surface	Pond	9	19.854643	-155.920886	4.33	0.44	85.7	5.51
4/25/2013	High	Surface	Pond	10	19.854801	-155.92021	50.9	2.27	91.1	1.68
4/25/2013	High	Surface	Pond	11	19.855272	-155.920116	49.5	2.60	76.9	3.39
4/25/2013	High	Surface	Pond	12	19.855032	-155.91988	28.1	1.37	77.7	2.10
4/25/2013	High	Surface	Pond	13	19.855487	-155.919914	56.2	3.48	177	6.05
4/25/2013	High	Surface	Pond	14	19.855285	-155.919695	53.5	2.36	158	2.4
4/25/2013	High	Surface	Pond	16	19.855847	-155.919248	57.8	2.55	175	2.12
4/25/2013	High	Surface	Pond	17	19.855664	-155.919047	56.2	2.54	185	1.36
4/25/2013	High	Surface	Pond	18	19.85617	-155.919252	30.1	1.73	85.2	9.23
4/25/2013	High	Surface	Pond	19	19.856031	-155.91904	56.8	2.46	167	1.19
4/25/2013	High	Surface	Pond	20	19.856262	-155.918899	56.2	2.50	118	2.04
4/26/2013	Low	Surface	Ocean	1	19.855243	-155.921625	55.0	2.25	131	1.92
4/26/2013	Low	Surface	Auwai	2	19.855016	-155.921581	50.1	2.15	113	2.66
4/26/2013	Low	Surface	Pond	3	19.854655	-155.921632	51.9	2.24	127	1.46
4/26/2013	Low	Surface	Pond	4	19.854627	-155.921366	47.0	2.15	209	2.67
4/26/2013	Low	Surface	Pond	5	19.85433	-155.921316	48.9	2.13	281	2.92

Date	Tide	Depth	Sample Area	Station	Lat	Lon	Nitrate +Nitrite (µmol/L)	Phosphate (µmol/L)	Silicate (µmol/L)	Ammonium (µmol/L)
4/26/2013	Low	Surface	Pond	6	19.854472	-155.921161	39.6	1.91	270	3.87
4/26/2013	Low	Surface	Pond	7	19.85464	-155.921087	51.9	2.17	174	3.33
4/26/2013	Low	Surface	Pond	8	19.854402	-155.920946	59.5	2.28	232	0.50
4/26/2013	Low	Surface	Pond	9	19.854643	-155.920886	46.8	2.42	231	2.15
4/26/2013	Low	Surface	Pond	10	19.854801	-155.92021	55.4	2.63	220	1.24
4/26/2013	Low	Surface	Pond	11	19.855272	-155.920116	54.8	2.75	263	2.29
4/26/2013	Low	Surface	Pond	12	19.855032	-155.91988	61.2	2.55	359	1.04
4/26/2013	Low	Surface	Pond	13	19.855487	-155.919914	62.5	2.74	261	1.03
4/26/2013	Low	Surface	Pond	14	19.855285	-155.919695	61.3	2.82	213	0.91
4/26/2013	Low	Surface	Pond	15	19.855572	-155.919487	60.4	2.72	241	1.83
4/26/2013	Low	Surface	Pond	16	19.855847	-155.919248	59.1	2.72	277	1.48
4/26/2013	Low	Surface	Pond	17	19.855664	-155.919047	59.1	2.77	237	0.92
4/26/2013	Low	Surface	Pond	18	19.85617	-155.919252	53.8	2.76	285	2.98
4/26/2013	Low	Surface	Pond	20	19.856262	-155.918899	55.2	2.60	220	1.87
4/26/2013	Low	Benthic	Pond	6	19.854472	-155.921161	50.8	2.17	243	2.97
4/26/2013	Low	Benthic	Pond	12	19.855032	-155.91988	26.5	1.91	243	3.33
4/26/2013	Low	Benthic	Pond	14	19.855285	-155.919695	29.6	2.45	188	3.95
4/26/2013	Low	Benthic	Pond	15	19.855572	-155.919487	22.1	1.88	155	4.31

APPENDIX B. FISH ABUNDANCE AND BIOMASS SUMMARY BY SPECIES

	Fish Abundance						
Fish Taxa	**12/5/2012**	**4/2/2013**	**6/20/2013**	**7/22/2013**	**9/7/2013**	**Mean**	**SD**
Abudefduf abdominalis	0	2	2	1	1	**1**	**1**
Abudefduf sordidus	0	2		1	1	**1**	**1**
Abudefduf vaigiensis	1	0	0	0	1	**0**	**1**
Acanthurus triostegus	7	8	1	9	9	**7**	**3**
Atherinomorus insularum	0	0	267	85	88	**88**	**109**
Blennidae	0	0	17	0	0	**3**	**8**
Caranx melampygus	0	0	1	1	5	**1**	**2**
Chanos chanos	0	0	3	80	0	**17**	**35**
Gobiidae	5	117	156	52	8	**68**	**67**
Kuhlia xenura	5588	8352	4696	5322	5017	**5,795**	**1468**
Lutjanus fulvus	9	1	30	13	2	**11**	**12**
Mugil cephalus	341	222	261	376	142	**268**	**94**
Mulloidichthys flavolineatus	3	10	8	1	6	**6**	**4**
Mulloidichthys vanicolensis	8	0	0	60	0	**14**	**26**
Polydactylus sexfilis	0	0	0	4	0	**1**	**2**
Sphyraena barracuda	5	9	1	0	5	**4**	**4**
Thalassoma purpureum	1	0	0	0	0	**0**	**0**
Grand Total (all taxa)	**5968**	**8723**	**5443**	**6005**	**5285**	**6,285**	**1399**

Fish Taxa	Fish Biomass (kg) 12/5/2012	4/2/2013	6/20/2013	7/22/2013	9/7/2013	Mean	SD
Abudefduf abdominalis	0	0	3	0	0	**1**	**1**
Abudefduf sordidus	0	3	0	1	3	**2**	**2**
Abudefduf vaigiensis	0	0	0	0	1	**0**	**1**
Acanthurus triostegus	0	0	0	0	0	**0**	**0**
Atherinomorus insularum	0	0	12	0	0	**2**	**5**
Blennidae	0	0	0	0	0	**0**	**0**
Caranx melampygus	0	0	0	0	0	**0**	**0**
Chanos chanos	0	0	5	6	0	**2**	**3**
Gobiidae	1	2	1	1	0	**1**	**1**
Kuhlia xenura	342	142	148	222	403	**252**	**117**
Lutjanus fulvus	3	0	17	2	0	**4**	**7**
Mugil cephalus	463	294	1167	1256	1150	**866**	**451**
Mulloidichthys flavolineatus	1	4	23	0	6	**7**	**9**
Mulloidichthys vanicolensis	3	0	0	3	0	**1**	**2**
Polydactylus sexfilis	0	0	0	0	0	**0**	**0**
Sphyraena barracuda	108	127	3	0	30	**53**	**60**
Thalassoma purpureum	0	0	0	0	0	**0**	**0**
Grand Total (all taxa)	**921**	**572**	**1379**	**1494**	**1595**	**1192**	**432**

APPENDIX C. LARVAL AND JUVENILE FISH AND INVERTEBRATE COUNTS FROM NEUSTON NET CASTS

Neuston Net Sampling Method	Date	Time	Sample ID	Flow Direction	Moon Phase	Mean Flow rate	Fish (larval)	Fish (juvenile)	Crab	Shrimp	Tanaeid	Assiminea	Theodoxus	other
24-hour	04/25/13	13:00	A-1-A	In	Full	-27	1	0	7	485	4	0	0	0
24-hour	04/25/13	13:00	A-1-B	In	Full	-27	0	0	8	328	0	0	0	0
24-hour	04/25/13	16:00	A-2-A	In	Full	-27	0	0	7	62	4	0	0	1
24-hour	04/25/13	16:00	A-2-B	In	Full	-27	3	0	13	76	9	2	2	0
24-hour	04/25/13	19:00	A-3-A	Out	Full	27	0	0	3675	1	0	5	0	0
24-hour	04/25/13	19:00	A-3-B	Out	Full	27	0	0	6636	0	2	44	22	1
24-hour	04/25/13	23:00	A-4-A	Out	Full	29	1	0	388	0	1	1	0	0
24-hour	04/25/13	23:00	A-4-B	Out	Full	29	0	0	411	0	2	2	3	0
24-hour	04/26/13	1:00	A-5-A	Out	Full	23	4	0	202	0	0	0	0	0
24-hour	04/26/13	1:00	A-5-B	Out	Full	23	2	1	161	0	0	0	0	0
24-hour	04/26/13	4:00	A-6-A	Out	Full	15	0	0	1	0	2	0	0	0
24-hour	04/26/13	4:00	A-6-B	Out	Full	15	0	0	0	0	1	1	0	0
24-hour	04/26/13	7:00	A-7-A	Out	Full	29	0	0	0	0	1	0	0	0
24-hour	04/26/13	7:00	A-7-B	Out	Full	29	0	0	0	0	0	0	0	0
24-hour	04/26/13	10:00	A-8-A	Out	Full	22	0	0	0	0	0	0	0	0
24-hour	04/26/13	10:00	A-8-B	Out	Full	22	0	0	0	0	0	0	0	0
24-hour	05/08/13	13:00	A-1-A	In	New	-6	0	0	1	6	0	0	0	0
24-hour	05/08/13	13:00	A-1-B	In	New	-6	0	0	2	26	0	0	0	0
24-hour	05/08/13	16:00	A-2-A	In	New	-14	1	0	0	5	0	4	0	0
24-hour	05/08/13	16:00	A-2-B	In	New	-14	0	0	0	0	0	2	0	0
24-hour	05/08/13	19:00	A-3-A	Out	New	28	0	1	1	0	0	82	52	8
24-hour	05/08/13	19:00	A-3-B	Out	New	28	0	0	0	0	0	79	24	3
24-hour	05/08/13	23:00	A-4-A	Out	New	33	0	0	846	1	0	9	13	0
24-hour	05/08/13	23:00	A-4-B	Out	New	33	0	0	679	0	0	5	16	0
24-hour	05/09/13	1:00	A-5-A	Out	New	19	0	0	1	0	0	0	43	0

Neuston Net Sampling Method	Date	Time	Sample ID	Flow Direction	Moon Phase	Mean Flow rate	Fish (larval)	Fish (juvenile)	Crab	Shrimp	Tanaeid	Assiminea	Theodoxus	other
24-hour	05/09/13	1:00	A-5-B	Out	New	19	0	0	0	0	0	11	47	0
24-hour	05/09/13	4:00	A-6-A	Out	New	14	0	0	0	0	0	0	36	0
24-hour	05/09/13	4:00	A-6-B	Out	New	14	0	0	1	1	0	2	25	0
24-hour	05/09/13	7:00	A-7-A	Out	New	29	0	0	0	1	0	0	8	0
24-hour	05/09/13	7:00	A-7-B	Out	New	29	0	0	0	0	0	0	2	0
Rising-Falling	05/24/13	11:20	A-1-A	Out	Full	8	0	0	0	0	0	11	0	0
Rising-Falling	05/24/13	11:27	A-1-B	Out	Full	8	0	0	0	0	1	0	0	0
Rising-Falling	05/24/13	11:38	A-1-C	Out	Full	8	1	0	0	0	0	0	0	0
Rising-Falling	05/24/13	14:49	A-2-A	In	Full	-63	5	0	5	152	3	1	0	0
Rising-Falling	05/24/13	15:19	A-2-B	In	Full	-63	1	0	13	111	2	0	0	0
Rising-Falling	05/24/13	15:34	A-2-C	In	Full	-63	6	2	12	98	3	0	0	0
Rising-Falling	06/20/13	6:00	A-1-A	Out	Full	36	0	0	1	0	1	0	0	0
Rising-Falling	06/20/13	6:09	A-1-B	Out	Full	36	0	0	0	0	0	1	0	0
Rising-Falling	06/20/13	6:19	A-1-C	Out	Full	36	0	0	1	0	0	1	0	1
Rising-Falling	06/20/13	11:54	A-2-A	In	Full	-28	0	9	1	210	0	0	0	0
Rising-Falling	06/20/13	12:02	A-2-B	In	Full	-28	2	2	0	174	0	0	0	0
Rising-Falling	06/20/13	12:12	A-2-C	In	Full	-28	3	13	6	191	0	0	0	0
Rising-Falling	07/22/13	6:53	A-1-A	Out	Full	24	0	0	0	5	0	0	0	0
Rising-Falling	07/22/13	6:59	A-1-B	Out	Full	24	0	0	0	0	0	0	0	0
Rising-Falling	07/22/13	7:15	A-1-C	Out	Full	24	0	0	0	0	0	0	0	0
Rising-Falling	07/22/13	13:42	A-2-A	In	Full	-21	1	0	0	114	0	0	0	0
Rising-Falling	07/22/13	13:48	A-2-B	In	Full	-21	0	0	0	60	0	0	0	0
Rising-Falling	07/22/13	14:15	A-2-C	In	Full	-21	0	3	0	128	0	0	0	0
24-hour	08/20/13	12:00	A-1-A	In	Full	-13	0	0	0	0	0	0	3	0
24-hour	08/20/13	12:00	A-1-B	In	Full	-13	0	0	0	0	0	1	2	0
24-hour	08/20/13	15:00	A-2-A	In	Full	-23	7	0	4	23	0	0	0	0
24-hour	08/20/13	15:00	A-2-B	In	Full	-23	0	0	0	18	0	0	0	0
24-hour	08/20/13	17:00	A-3-A	Out	Full	8	0	0	0	0	0	0	0	0
24-hour	08/20/13	17:00	A-3-B	Out	Full	8	0	0	0	0	0	1	0	0

Neuston Net Sampling Method	Date	Time	Sample ID	Flow Direction	Moon Phase	Mean Flow rate	Fish (larval)	Fish (juvenile)	Crab	Shrimp	Tanaeid	Assiminea	Theodoxus	other
24-hour	08/20/13	20:00	A-4-A	Out	Full	25	0	0	0	0	0	10	3	0
24-hour	08/20/13	20:00	A-4-B	Out	Full	25	0	0	0	0	0	13	6	0
24-hour	08/20/13	23:00	A-5-A	Out	Full	21	0	0	0	0	0	6	1	0
24-hour	08/20/13	23:00	A-5-B	Out	Full	21	0	0	0	0	0	0	0	0
24-hour	08/21/13	1:00	A-6-A	Out	Full	11	0	0	0	0	0	0	1	0
24-hour	08/21/13	1:00	A-6-B	Out	Full	11	0	0	0	0	0	2	0	0
24-hour	08/21/13	3:00	A-7-A	In	Full	-14	0	0	0	0	0	0	0	0
24-hour	08/21/13	3:00	A-7-B	In	Full	-14	0	0	1	0	0	2	4	0
24-hour	08/21/13	8:00	A-9-A	Out	Full	22	0	0	0	0	0	0	0	0
24-hour	08/21/13	8:00	A-9-B	Out	Full	22	0	0	0	0	0	1	0	0
24-hour	08/21/13	10:00	A-10-A	Out	Full	20	1	0	0	0	0	0	0	0
24-hour	08/21/13	10:00	A-10-B	Out	Full	20	0	0	0	0	0	2	0	0
24-hour	08/21/13	12:00	A-10-A	Out	Full	8	0	0	0	0	0	1	2	0
24-hour	08/21/13	12:00	A-10-B	Out	Full	8	0	0	0	0	0	1	0	0