Division of Aquatic Resources
Department of Land and Natural Resources

Aquatic Invasive Species Local Action Strategies
NOAA Coral Reef Management Grant

Hull Fouling Surveys of Recreational Boats in Hawaii

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Executive Summary

Limited information exists on hull fouling as a vector for the introduction of aquatic invasive species and even less is known about the dynamics and risks that hull fouling on recreational vessels pose. This hull fouling survey of recreational vessels project gathered baseline information and assessed management options for recreational vessels as a vector for aquatic invasive species in Hawaii. The project consisted of five components: 1) rapid assessment surveys of fouling levels, using a scale of zero (clean) to five (heavily fouled), were conducted on recreational vessels throughout the State (n=2135) with information on vessel size and type also being obtained; 2) vessel questionnaires and interviews were conducted to gather hull husbandry practices and boat movement (n=64); 3) underwater hulls surveys were conducted (n=53) by using eight transect points, after which the level of fouling was averaged, the presence of 12 broad biofouling groups were determined, and the position of fouling and above water grading were also correlated; 4) level of fouling and a grading of the general maintenance of vessels were taken from a distance with use of different optical levels, these levels were then correlated with up close grading and actual under water level of fouling (n=24); 5) recreational vessel grounding were investigated over the course of the study (n=9).

From the surveys, wide ranges of Level of Fouling (LoF) were found on recreational vessels in Hawaii. Overall, fouling levels were low with the majority of vessels (66%) having no to light fouling. There were 11% of vessels that showed extensive to very heavy fouling, with some of the vessels having 100% coverage. General trends existed for groups of vessels. Racing sailboats and mega yachts showed very low levels of fouling. Averaging out the LoF shows motorboats have slightly less fouling than sailboats and fouling decreases with the size of the vessel. Wide variety of LoF occurred between harbors. Harbors on the Island of Hawaii, Honokohau and Hilo, had some of the lowest LoF which may be caused by the low salinity levels which are believed to occur there. Private yacht clubs showed very low LoF while Haleiwa and Keehi showed the highest levels.

Vessel questionnaires showed that all vessels had antifouling paint applied. The majority responded that it was applied within the last five years, with two to three years being the average. A wide variety of antifouling paints were used with almost all containing cuprous oxide. LoF for paint type was varied but some showed less fouling. A more reliable indicator for LoF would be age of paint in which fouling increased with

age. Surveys indicated that hull cleaning was occurring on a regular basis, with the frequency of cleanings varying greatly. The majority of vessels were cleaned between one and six times a year with a few cleaned every month and some cleaned on a 12 to 18 month schedule.

Travel patterns indicated that 21% of Hawaii vessels traveled to a neighbor island from their home marina with none travelling out of state. 40% of out of state vessels travel to other islands in Hawaii. Though a few stayed for a few years, the majority stayed for less than two weeks. Majority of out of state boats came from the East and had a slightly higher LoF than those coming from the West. The direction a vessel is from may not be a good indicator of risk because travel patterns are very complex.

Hull surveys showed that above water LoF grading system can be used as a convenient management tool. Although the actual fouling was almost always higher than the above water grading, a strong correlation for matching up was shown. It can be used as a way to estimate the actual level of fouling and pinpoint high risk vessels without having to enter the water or use specialized equipment to inspect the vessels.

Of the vessels that were surveyed, slime was the most common broad biofouling group present followed by macro algae, tubeworms and micro algae. Barnacles, molluscs, bryozoans and sponges also showed a strong presence. Presence of biofouling groups were similar to other studies conducted. LoF showed a trend of increasing going from bow to stern and in almost all cases running gear had the highest fouling rate.

Vessel profiling showed to be a good tool to estimate the LoF of a vessel. This study showed that there is a very strong correlation between a grading of how the above water portions of a vessel are maintained and the actual LoF of a vessel. A generalization of this would be well maintained vessels have low fouling, and neglected or unmaintained vessels have high fouling levels. Long distance grading of LoF was shown as an unusable tool. However, grading for above water portions of the vessel at a distance correlated exactly to up close grading when using high power optics. Vessel profiling can be used as a tool at a distance to estimate LoF and possibly pinpoint high risk vessels.

Vessel grounding was found to be a high risk for introduction of aquatic invasive species. Majority of the vessels had high LoF and one vessel was carrying 2 types of alien invertebrates and 2 alien algae species. Higher priority will be given by Division of Aquatic Resources to this mode of introduction and areas will be monitored to see if alien species become established. A general lack of awareness of the problems of aquatic invasive species by vessel owners and operators, harbor personnel and general

public was observed throughout this project. Outreach became an important priority and information about the threat of aquatic invasive species and best management advice was given on not spreading or introducing these species into our state.

Studies have shown that equipment such as pole camera and vessel wrapping system can be effective tools in monitoring for and addressing recreational hull fouling. Pole camera is an efficient tool to get an actual look at the underwater portions of a vessel without the hazard of harbor diving. Vessel wrapping system is another efficient tool to address high risk vessels by allowing for a way to quarantine and treat while in water.

Past surveys and research suggest that certain recreational vessel characteristics can be used to pinpoint high risk vessels. Two preliminary risk matrixes were developed to pinpoint high risk vessels and to create a management tool for the State. One addresses Hawaii vessel and another for out of state vessels. The matrixes incorporated type of vessel, last antifouling paint application, last hull husbandry practices and LoF. The matrixes also provide for appropriate action to take such as in-water cleaning, quarantine and treat, haul out, apply new antifouling paint and stop no action needed. Risk matrixes can be refined and improved as more research is done. The adoption of strong regulations would be the key to minimizing the introductions of aquatic invasive species into the State. Until this occurs, outreach, collaboration with stakeholders, and working with high risk vessels would need to be done.

In summary, the project looked at the degree of fouling of recreational vessel in and coming into Hawaii, obtained information on hull husbandry, took baseline data on species richness of biofouling groups and looked into preliminary management tools to assist resource managers to address this vector. Throughout this project, a capacity was built in the State's Department of Land and Natural Resources/ Division of Aquatic Resources through training, acquiring and testing of specialized equipment and the development of management tools to address this vector in Hawaii.

Introduction

Aquatic Invasive species are a serious threat to aquatic ecosystems around the world causing severe ecological and economic damage. Hawaii has seen the negative impact of introduced algae that are displacing native marine organisms and smothering coral reefs. With the isolation of the Hawaiian Islands all introduced species have the potential to become invasive. Prevention and border control measures are key elements to the management of aquatic invasive species because once established they are difficult and expensive to control or eradicate.

The movement of vessels is considered the major transporter for aquatic invasive species around the world. Ballast water, which is taken up and discharged as needed for stability by vessels, is commonly thought of as the biggest cause, but as more research is being conducted hull fouling is being seen as a larger vector for aquatic invasive species than previously thought.

Hull fouling or biological fouling consists of algae and invertebrates that grow on the submerged portions of vessels hulls and gear that is in regular contact with the ocean. It starts off as a layer of slime consisting of bacteria and microscopic algae that accumulate on an object shortly after immersion, followed by the gradual attachment of macro fouling species. Without maintenance, huge biofouling communities can grow on the bottom of the vessel.

Research done in Hawaii has shown that the majority of introduced marine invertebrates most likely arrived through hull fouling (Eldredge and Carlton 2002). This often overlooked pathway is both difficult to monitor and manage. Most of the focus for research has been on large commercial vessels. These vessels, as a result of regulations, short residency times and serious concerns for fuel prices keep hull fouling to a minimum(Godwin and Eldredge 2001, Ruiz et al. 2006, Takata et al. 2006). In general, these characteristics do not apply to recreational vessels. This vector has been poorly studied, but research has shown that it could be a major part in the spread of aquatic invasive species (Godwin et al. 2004). Hawaii has approximately 15,000 registered recreational boats and a number of transient vessels that visit the islands. It is important for the biosecurity of Hawaii that the risk of these vessels be researched and documented.

The State of Hawaii's Department of Land and Natural Resource is the lead state agency for preventing the introduction of hull fouling organisms. It is currently being addressed as a high priority and working with the Alien Aquatic Organism Task Force (AAOTF) to develop a comprehensive plan for preventing the introduction and dispersal

of alien aquatic organisms found on the hulls of vessels. The AAOTF includes representatives from state and federal agencies, shipping industries, the scientific community and non-government organizations. The Division of Aquatic Resource is currently managing hull fouling by working with stakeholders to voluntarily implement best management practices and addressing high risk vessels and loosely relying on a "risk matrix" to pinpoint high risk vessels and deal with them on a case by case basis (Godwin 2005). The Northwest Hawaiian Islands, Papahanaumokuakea Marine National Monument, has a very strong invasive species management program with zero tolerance for aquatic invasive species. 100% of vessels (excluding US Coast Guard and US Navy) require a hull and invasive species inspection. The Monument has very few non-native species and rigorous inspection of vessel hulls, ballast water, ancillary and scientific gear is done to maintain the biosecurity of area.

Goal of this project was to gather baseline information, assess the importance of and look into management options for recreational vessels as a vector for aquatic invasive species in Hawaii. This project will look at the degree of fouling of recreational vessel in and coming into Hawaii, get information on hull husbandry, take baseline data on species richness of biofouling groups and look into preliminary management tools to assist resource managers to address this vector.

METHODS

Many of the survey techniques were adopted from a pilot study done in San Francisco Bay to characterize the risk of species transfer on recreational boats via hull fouling (Davidson et al. 2008). Rapid survey techniques were employed to cover a high number of vessels to gather baseline data on the general dynamics of recreational hull fouling. Survey consisted of five parts:

1. Level of Fouling
2. Vessel Questionnaire
3. Hull Survey
4. Long distance and vessel profiling
5. Investigate recreational hull grounds

1. Level of Fouling:

Level of Fouling (LoF) rank was conducted by walking or navigating a small vessel through marinas and harbors categorizing vessels by a modified form of grading developed by Floerl et al. (2005). The LoF was observed by visibly looking across the whole length of one side of a vessels water line and applying a rank from zero (clean) to five (heavily fouled).

Ranking used were;

0- No visible Fouling
1- Hull partially of completely covered in slime but no macro fouling
2- Light fouling 1-5%
3- Considerable fouling 6-25%
4- Extensive fouling 25-49%
5- Very heavy fouling 50-100%

Information was also taken on type of vessel Sail (S) or Motor (M), harbor in which vessel was located and size of the vessel correlated to number of paces.

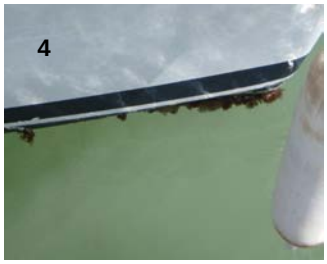
S- Small <10 paces
M- Medium 10-20 paces
L- Large >20 paces

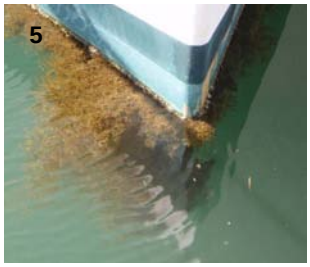
Work sheet with pictures of grading and survey information was carried by surveyor for consistency.

LoF- Level of Fouling Ranks

0 No visible Fouling
1 Hull partially or completely covered in slime fouling, no macro fouling.
2 Light fouling 1-5%
3 Considerable fouling 6- 24%
4 Extensive fouling 25-49%
5 Very heavy fouling 50-100%

Size-S (Small <10paces), M (Medium 10-20paces), L (Large >20paces)
Type-M (Motor), S (Sail), C (Commercial), O (Other)





All vessels at a studied marina were ranked unless a bad or obstructed view didn't allow for a good ranking. Two harbors were also duplicated for comparison of results.



2. Vessel Questionnaire:
Questionnaire on hull husbandry practices and boat movements were made available at harbors master office with a drop box for boaters to voluntarily fill out the forms. Also, interviews of vessel owners and operators were conducted at the docks. Questions asked on the survey were:

1. Type of vessel
2. Present and home marina
3. Boat movement in the last two years including travel out of home marina area, travel to Neighbor Island, and travel into and out of state including duration of travel.
4. Last paint application of antifouling paint and product type
5. Hull maintenance practices done including type, what done and how often and cost.
6. If they allow an underwater survey of boat hull.

Throughout the surveys, a top priority was giving out information about the threat of aquatic invasive species for outreach and given best management advice on not spreading or introducing these species into the state.

3. Hull Survey:
Vessels in which owners or operators allowed an underwater survey of their vessel, were sampled by taking eight transect points along the length mid draft of the vessel of approximately 12x12 inches. Majority of vessels were surveyed using an underwater pole camera which is basically an underwater video camera on the end of a pole and video observed from the surface. When pole camera was unable to reach the vessels hulls, free diving was used or the Division of Aquatic Resources's remote operated vehicle which sends back video to the driver. Mid depth photo quadrant of eight random spots along one side of a vessel were taken from the bow to stern with a photo quadrant

of the running gear also taken. This was done to correlate above water and below water rankings.



A subset of samples was used to get a percent cover of broad functional groups. Transects were reviewed for the presence of 12 broad biofouling groups,

1. Slime
2. Micro-algae
3. Macro-algae
4. Crabs
5. Hydroids
6. Tubeworms
7. Bryozoans
8. Sponge
9. Molluscs
10. Barnacles
11. Anemone
12. Tunicates

Broad fouling groups were chosen on what the author felt could be recognizable by a familiarity with marine organisms or that could be taught easily.

4. Long Distance and Vessel Profiling:
Level of fouling and a grading of general up keep or maintenance of the above water portions of the deck were was observed at a distance of approximately 100 yards away with binoculars, high powered binoculars, spotting scope and naked eye. The vessel was then resurveyed up close for general up keep, LoF and under water LoF. The grading scale used for the above water general up keep or maintenance:

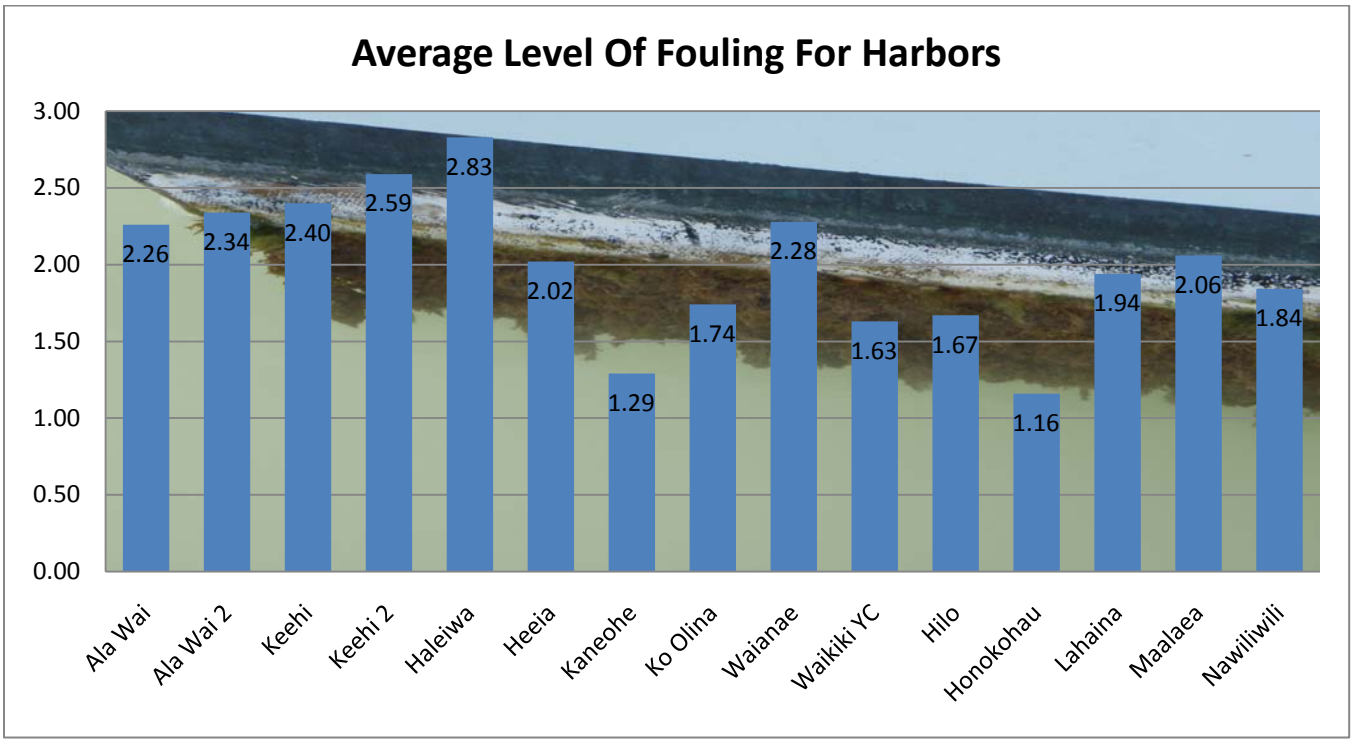
1- New boat or very well maintained
2- Well maintained
3- Maintained
4- Not maintained



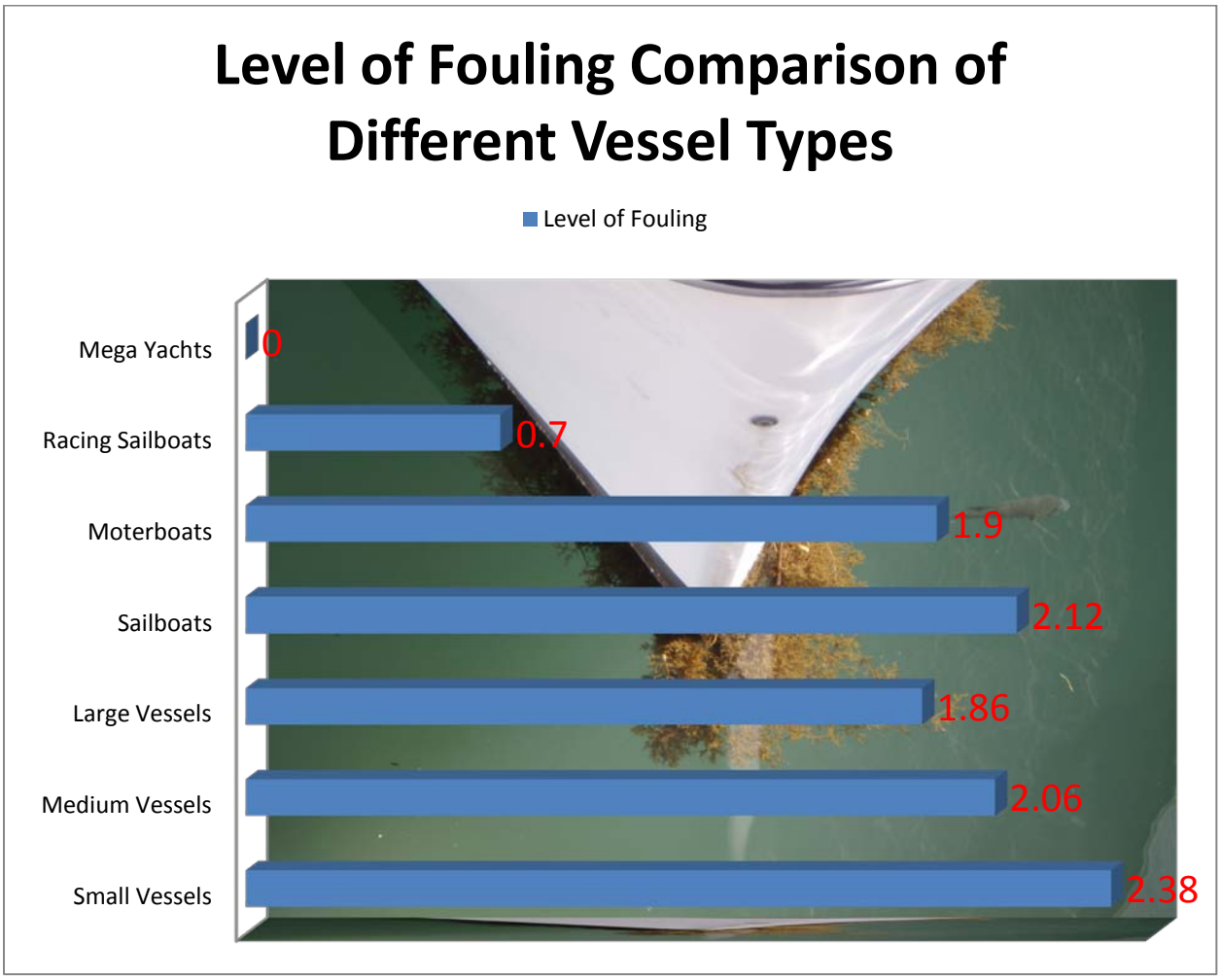
5. Investigate Recreational Hull Grounds:
Hawaii gets several recreational vessel groundings each year, 9 groundings were investigated and LoF and travel and husbandry information were taken. The potential for aquatic invasive species transfer was also looked into.

RESULTS

1. Level of fouling rapid assessment:
A total of 2135 vessels were ranked using the rapid LoF grading with an average of 2.0 for all vessels surveyed. A wide range of LoF fouling was observed between vessels with an entire range of 0 to 5 in all harbors except for the ones on the Big Island. Wide variation in the averages of LoF occurred between harbors with Kaneohe Yacht Club and Honokohau had the lowest while Haleiwa and Keehi showed the highest. Replicate survey of two harbors showed very similar levels of fouling.



Averages between vessel sizes showed that small vessel had the highest level of fouling followed by medium then large. Sailboats had a higher level of fouling than motorboats but racing sailboats showed a very low level of fouling. Two Mega Yachts were surveyed and showed no fouling.



Distribution for Fouling rankings found that most vessels fell within 1, 2, 3 ranking. 61% were in one and two rankings indicating very low or light fouling.

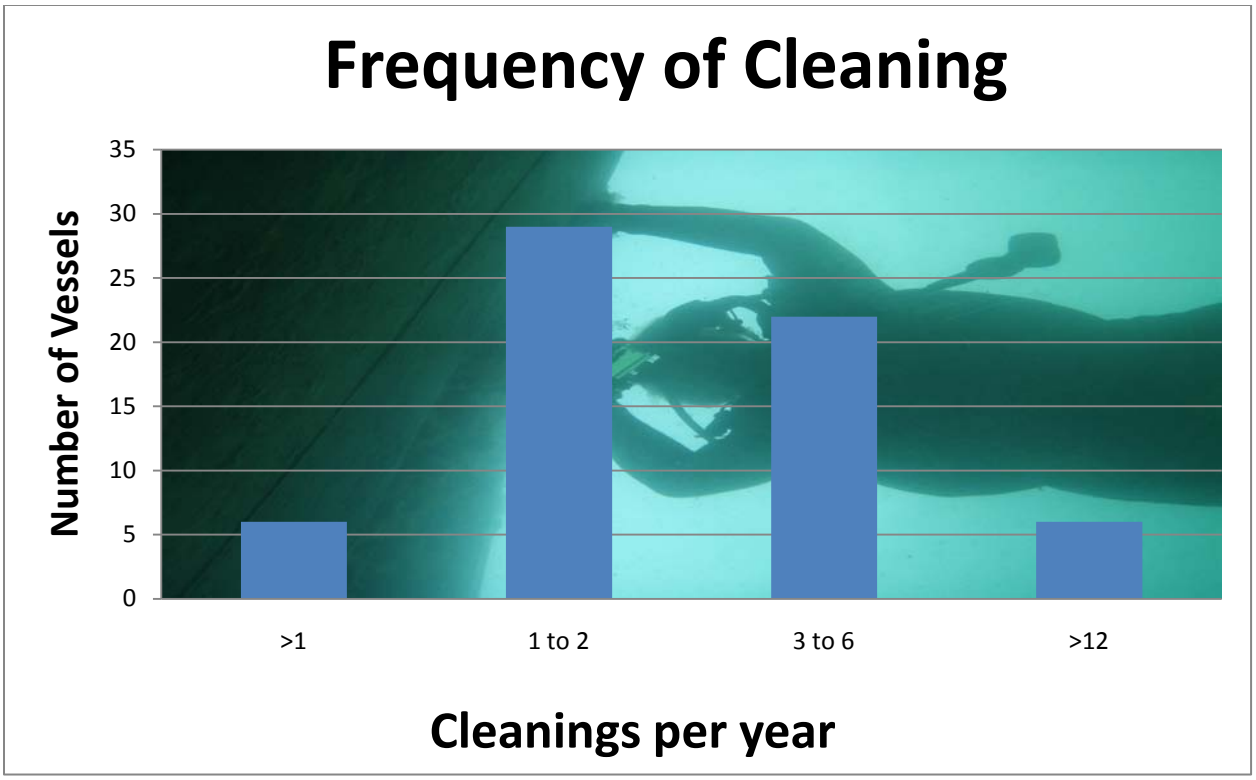
Distribution of Fouling Ranks

Fouling Rank	Number of Vessels	% of Vessels
0	119	5
1	767	30
2	783	31
3	574	23
4	185	7
5	106	4

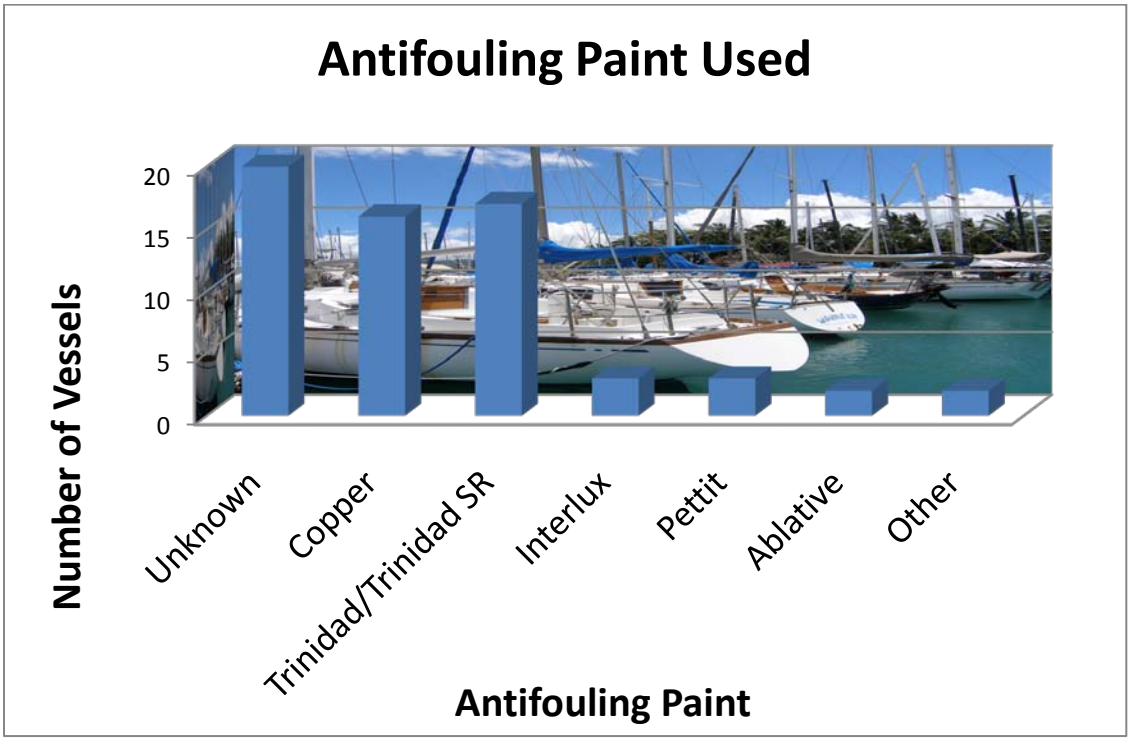
2. Vessel Questionnaire:

Few questioners were filled out at harbor master drop boxes, and nearly all of the questionnaires were gotten by interviewing vessel owner and operators in the course of walking through the harbors. A total of 64 questionnaires were filled out with 33 from Hawaii, 30 from out of state and one answered unknown. They were asked to fill out travel movements for only the last two years. 21% of the Hawaii vessels traveled to other islands and did not travel out of state. Out of state vessels indicated that 40% of them travel to other Islands. Most of these vessels stay for less than two weeks but the average is pushed up to six weeks because some indicated that they stayed here for several years.

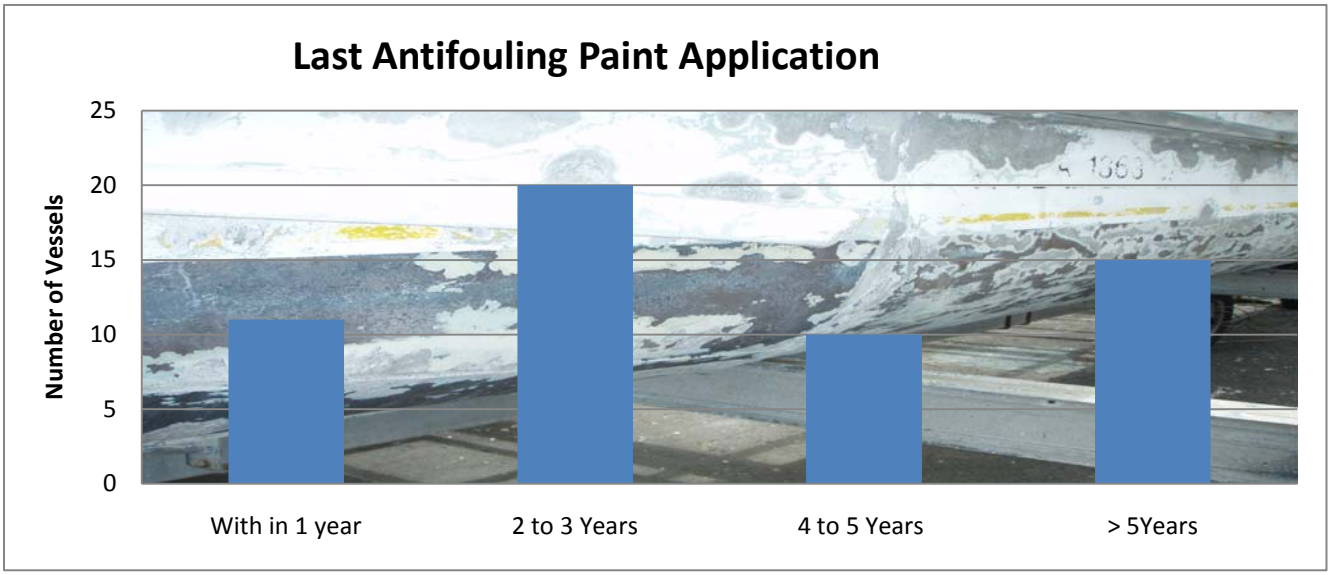
Nearly all responded that they preformed some type of hull maintenance or in-water cleaning but at a wide range of times. The majority of people clean their hulls one to two times a year followed by those who did it three to six times. A few clean their hulls monthly and some bi annually. 78% clean their vessel in the harbor while the rest indicated that they clean out of the harbor at anchor or some other spot. Average for people to pay for in-water cleaning was $53. Interviews with hull cleaning divers say they charge an approximately $1.50 to $2 per foot depending on how bad the boat is fouled, and that business was very good.



All vessels indicated that they had antifouling hull paint with a majority having had it applied less than five years ago. Of those who knew what type of antifouling paint was used, Trinidad and Trinidad SR were the most popular followed by copper or cuprous oxide.

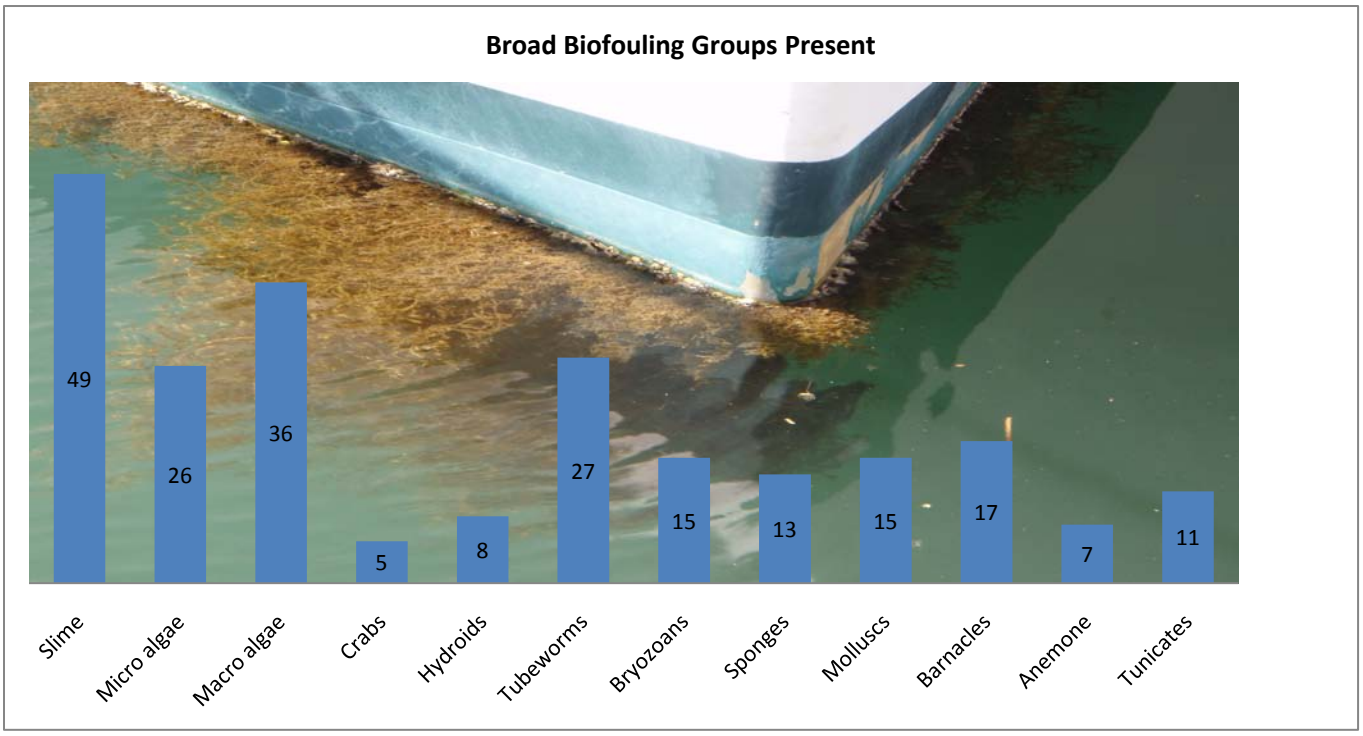


For last application of antifouling paint the majority responded that it was applied within the last five years, with two to three years being the average.

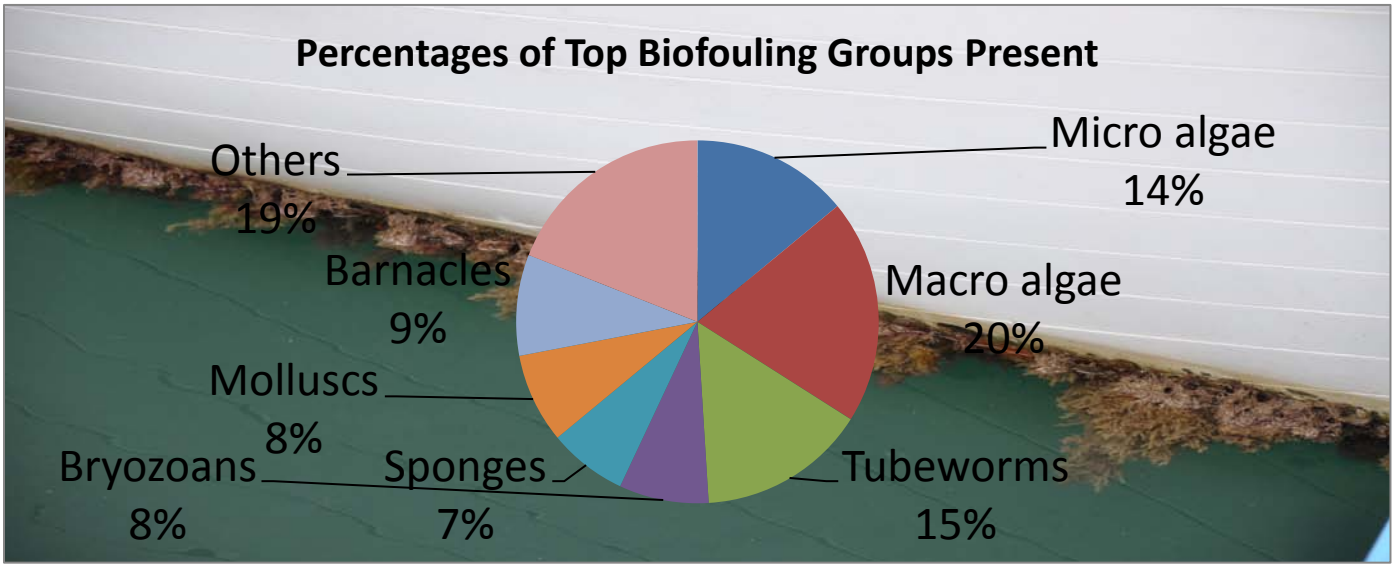


3. Hull Survey:

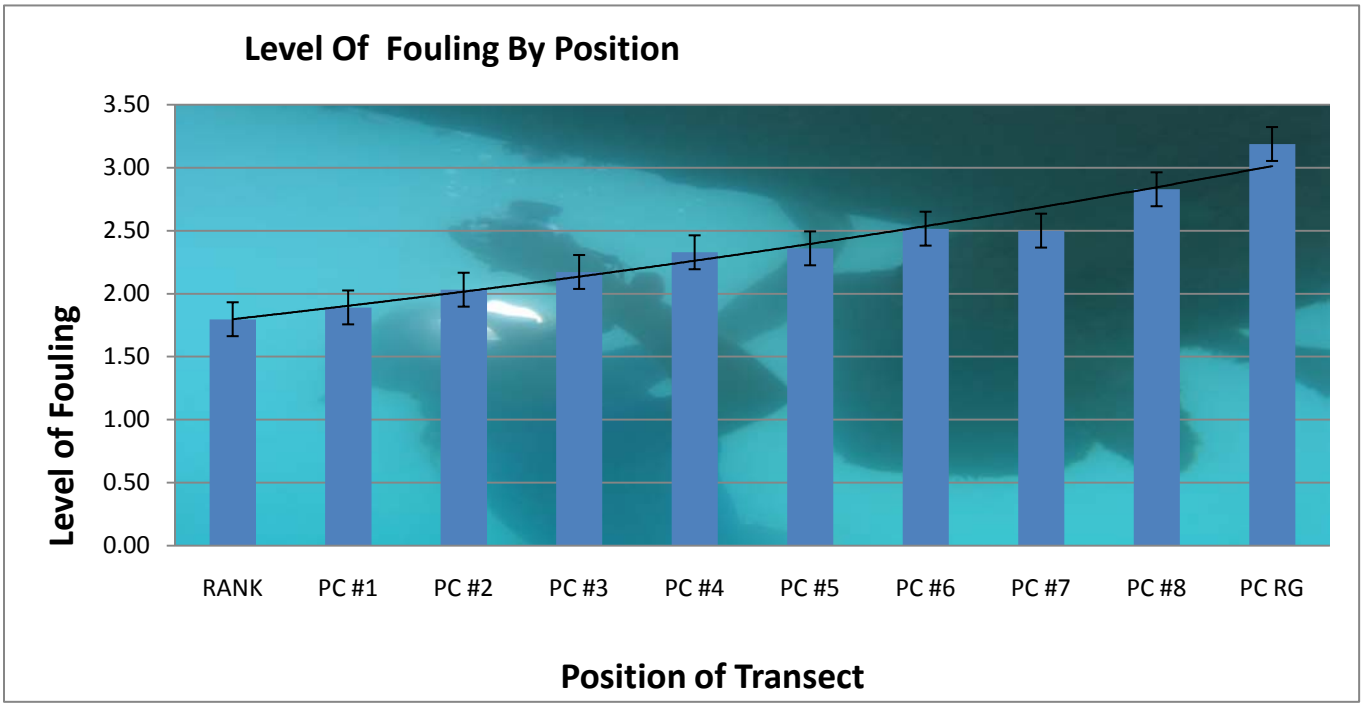
Data from 53 vessels were analyzed 23 from Hawaii and 30 from out of state. Identification of broad biofouling groups were not made by taxonomic experts but were rather field observations made by camera, quick underwater observations or reviewed later from photos or video recordings. Biofouling group that was most common was slime by macro algae, tubeworms, and micro algae.



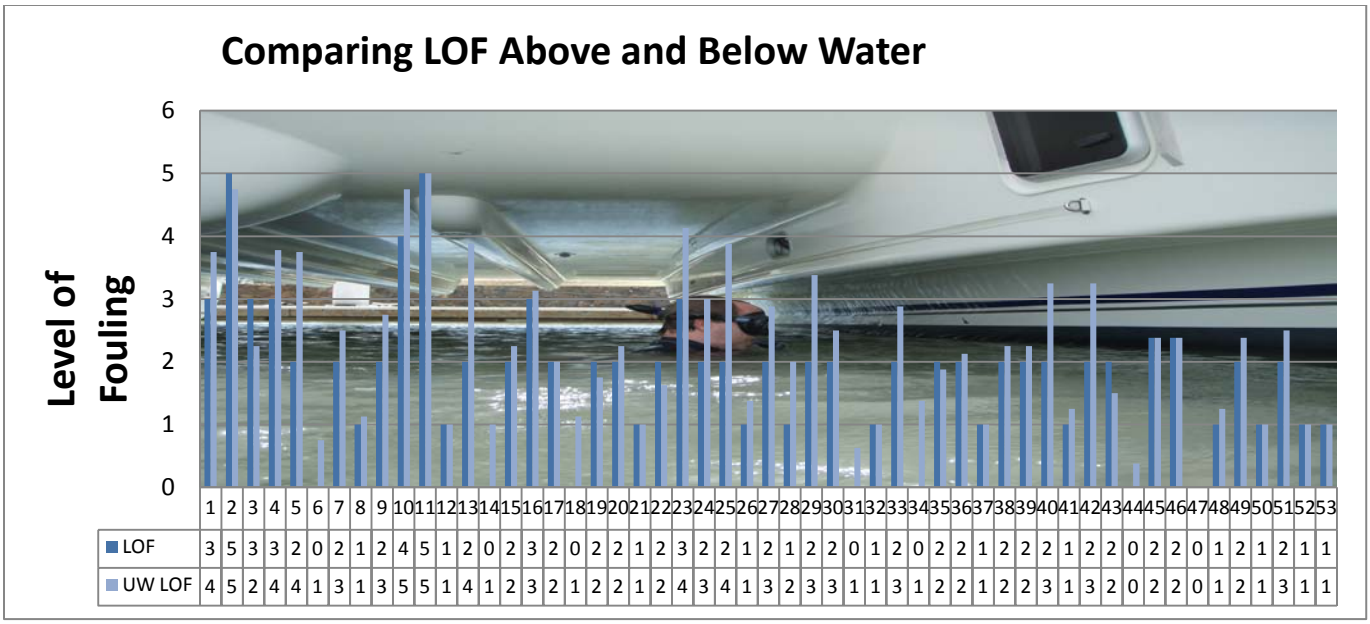
Macro algae had the highest percentage of macro fouling with 20% followed by tubeworms at 15% and barnacles at 9%.



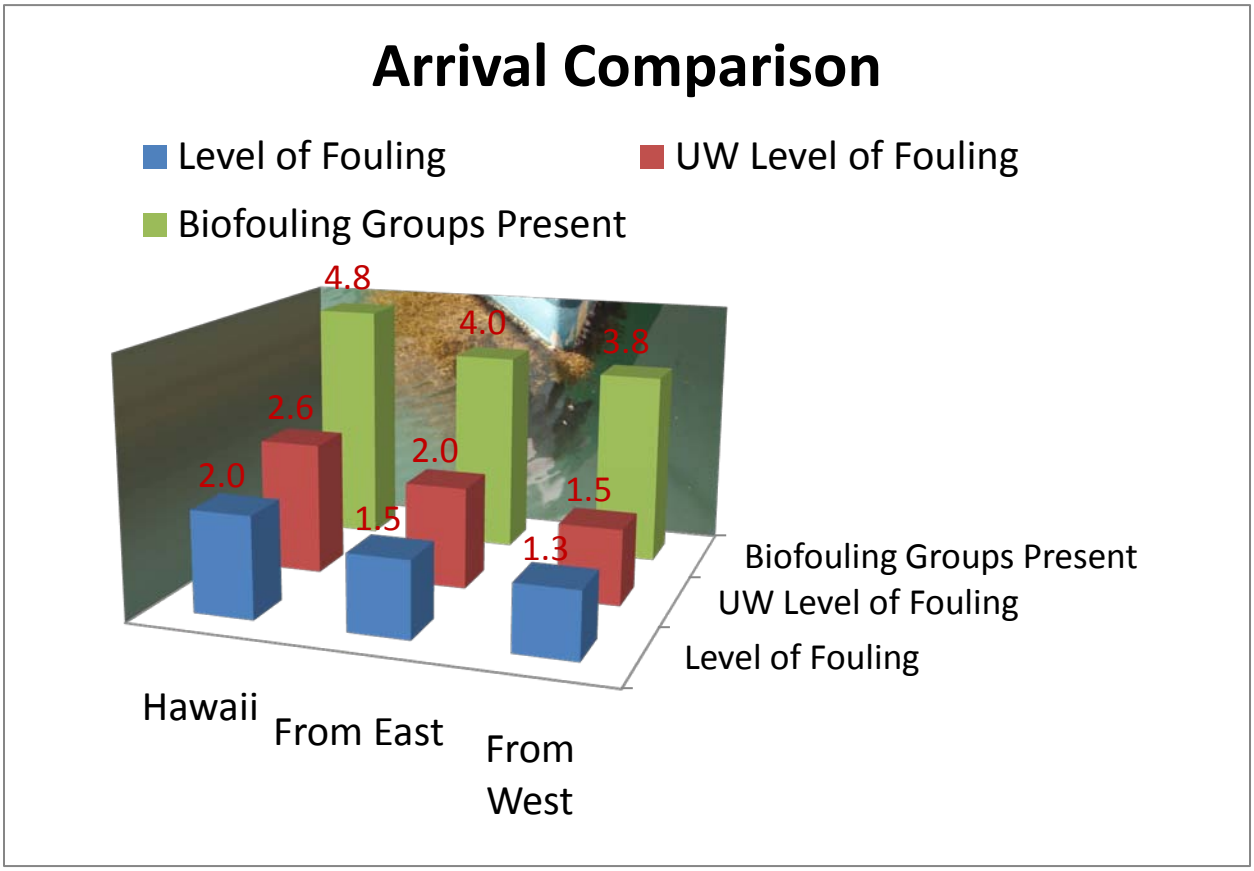
Averaging out the level of fouling by position under the vessel showed an increasing amount of fouling as you go from bow to stern. The running gear had the highest level of fouling.



Comparison of above water ranking of LoF and below water LoF did not match up exactly but did show a very good correlation if you factor in that the below water Lof was almost always higher.

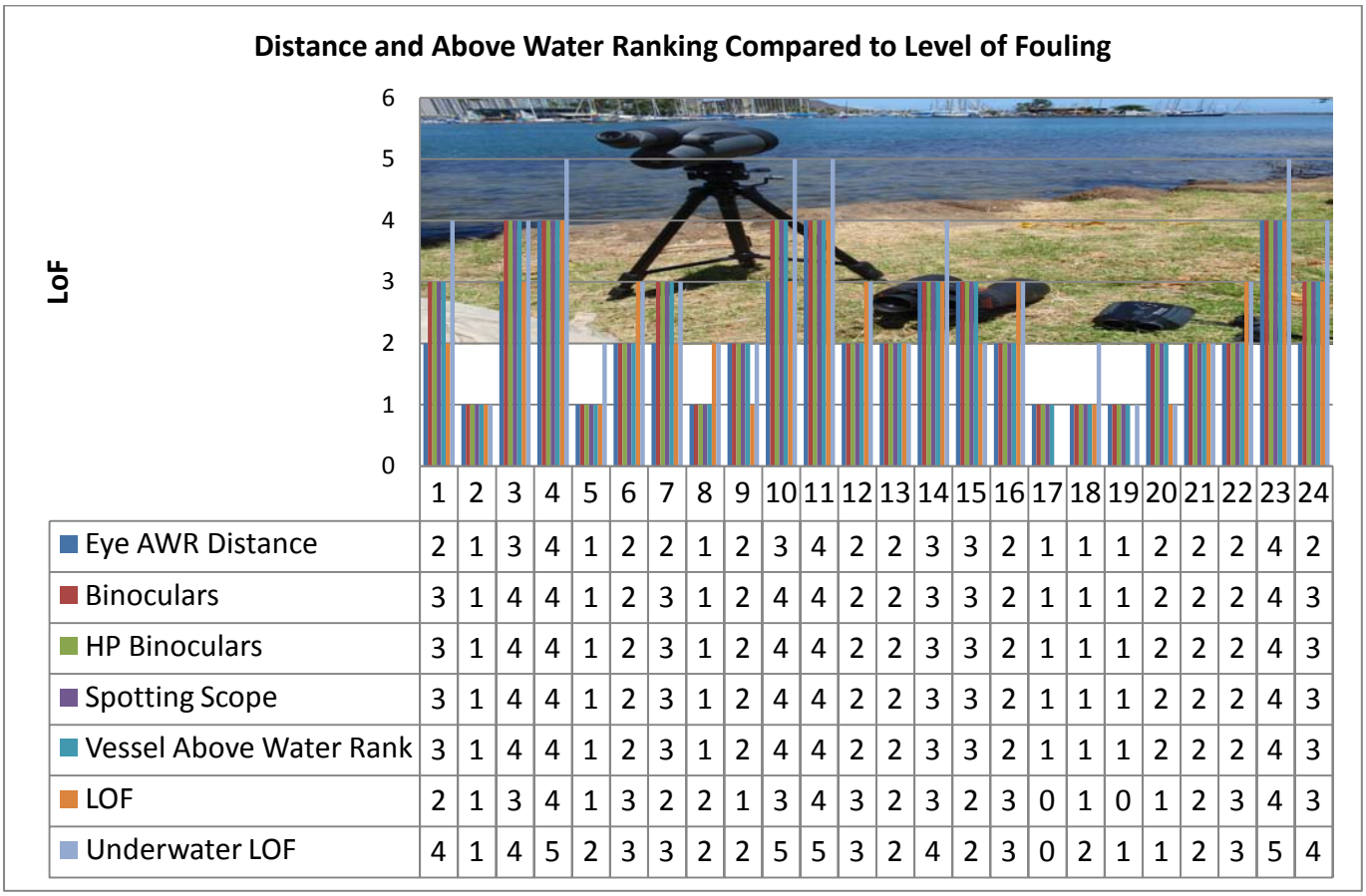


Vessels to Hawaii from the East (California, Washington, etc.) had slightly more biofouling groups present and a higher level of fouling than vessels coming from the West (Guam, New Zealand, etc.). Averages for Hawaii vessels were higher than both.



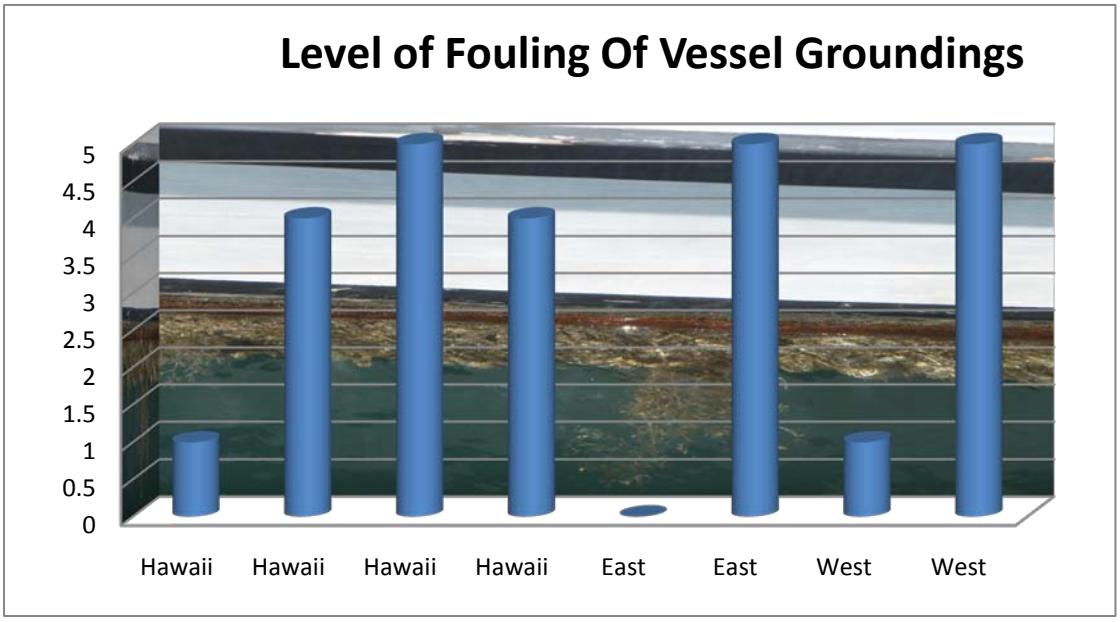
4. Long Distance and Vessel Profiling:
Long distance LOF grading showed 0 results, and was noted that it was impossible to estimate the level of fouling from a distance even with the aid of high power optics during the course of the survey.

Comparing distance and close up of general up keep or maintenance of the above water portions of the vessel was exactly the same when using the high power optic. It did not matter if it was the binoculars, high powered binoculars or the spotting scope. At 100 yards unassisted optic grading was not as effective. Above water up keep showed a very strong correlation to the underwater LoF.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Eye AWR Distance	2	1	3	4	1	2	2	1	2	3	4	2	2	3	3	2	1	1	1	2	2	2	4	2
Binoculars	3	1	4	4	1	2	3	1	2	4	4	2	2	3	3	2	1	1	1	2	2	2	4	3
HP Binoculars	3	1	4	4	1	2	3	1	2	4	4	2	2	3	3	2	1	1	1	2	2	2	4	3
Spotting Scope	3	1	4	4	1	2	3	1	2	4	4	2	2	3	3	2	1	1	1	2	2	2	4	3
Vessel Above Water Rank	3	1	4	4	1	2	3	1	2	4	4	2	2	3	3	2	1	1	1	2	2	2	4	3
LOF	2	1	3	4	1	3	2	2	1	3	4	3	2	3	2	3	0	1	0	1	2	3	4	3
Underwater LOF	4	1	4	5	2	3	3	2	2	5	5	3	2	4	2	3	0	2	1	1	2	3	5	4

5. Investigate Recreational Hull Grounds:
Nine vessel groundings were investigated over the course of the project. One vessel was unable to locate while the others showed a varied level of fouling.



One case was investigated by the Division's Aquatic Invasive Field Team and they collected four species of barnacles, five species of crabs and three species of algae. Invertebrate samples were Identified by Scott Godwin, two were alien species but already established in Hawaii and the rest were cosmopolitan pelagic. Dr. Alison Sherwood of the Botany Department at the University of Hawaii using identification lists and DNA analysis identified two of the three algae species as possible new alien species introductions to Hawaii. Further DNA analysis is being conducted to properly Identify.

Biofouling Group	Name	Comments
Crab	*Planes cyaneus*	Cosmopolitan species
Crab	*Grapsus tenuicrustatus*	Cosmopolitan species
Crab	*Plagus depressa tuberculata*	Cosmopolitan species
Barnacle	*Balanidae trigonus*	Established alien species
Barnacle	*Megabalanus tintinabulum*	Cosmopolitan species
Barnacle	*Balanus reticulatus*	Established alien species
Barnacle	*Lepas anatifera*	Cosmopolitan species
Barnacle	*Conchoderma virginatum*	Cosmopolitan species
Macro algae	Enteromorpha form of Ulva	Need more DNA analysis: New alien species?
Macro algae	*Ulva* Sp.	Need more DNA analysis
Macro algae	Filamentous red algae	Need more DNA analysis: New alien species?

DISCUSION

Hull fouling by recreational vessels as a vector for transmission of aquatic invasive species is complicated and there are many unknown dynamics. Study found that a wide range of LoF was observed throughout Hawaii's recreational vessels but some trends were observed. Distribution for fouling rankings found that most vessels fell within 1, 2, 3 ranking. A majority or 66% of the vessels showed very light or no fouling. A number of vessels (n=106, 4%) showed very heavy fouling. These vessels should be considered high risk for the introduction of aquatic invasive species if they are moved around.

The harbor with the lowest LoF was Honokohau. Dr. Bill Walsh, DAR Kona Biologist, brought to attention that the huge flush of fresh water that flows through the harbor may play a big role in keeping fouling down. The Division's vessel in this harbor also never accumulates high levels of fouling. Hilo also had low levels of fouling which could be attributed to the large flow of fresh water through it. Both of these harbors didn't have any heavily fouled or five ranked vessels. Study in San Francisco Bay showed that Antioch, which was the most heavily influenced by freshwater of the six marinas surveyed, had the lowest level of fouling (Davidson et al. 2008) Fresh water is believed to reduce hull fouling and has been used as a management tool. Before the USS Missouri sailed to Hawaii it was towed through a fresh water river to reduce the level of fouling (Brock at el. 1999). Harbors such as the Ala Wai and Nawiliwili also get strong fresh water flushes but had higher LoF indicating that other factors are also involved.

The private yacht clubs Kaneohe, Waikiki and Ko Olina also had low LoF. Harbor agents here speculated that the lower LoF could be due to enforcement of "buoy run" rules in which a vessel in their harbors must demonstrate that they can navigate to a certain spot and return monthly. It is long thought that vessels that are stationery, poorly maintained and moored in harbors that provide ideal conditions for the establishment of hull fouling organism have the highest level of fouling (Goodwin, 2008) A preliminary study of vessels in the Port of Oakland showed that eight of nine container ships had hull fouling but that the levels of fouling were low. Short time in port and relatively fast speeds were common factors of these vessels and could play a large factor in the fouling levels that occur (Ruiz et al. 2005, Davidson et al. 2009)

Two groups of vessels seem to be low risk, mega yachts and racing sailboats. Only a small sample of mega yachts were sampled, N=2, but the hulls were free of any fouling. Racing sail boats from the Transpacifc and Pacific Cup showed very low LoF and combined with short stay in Hawaii lowers risk of introducing aquatic invasive species. Study shows that there is a wide range of LoF for each type of vessel, but a strong trend

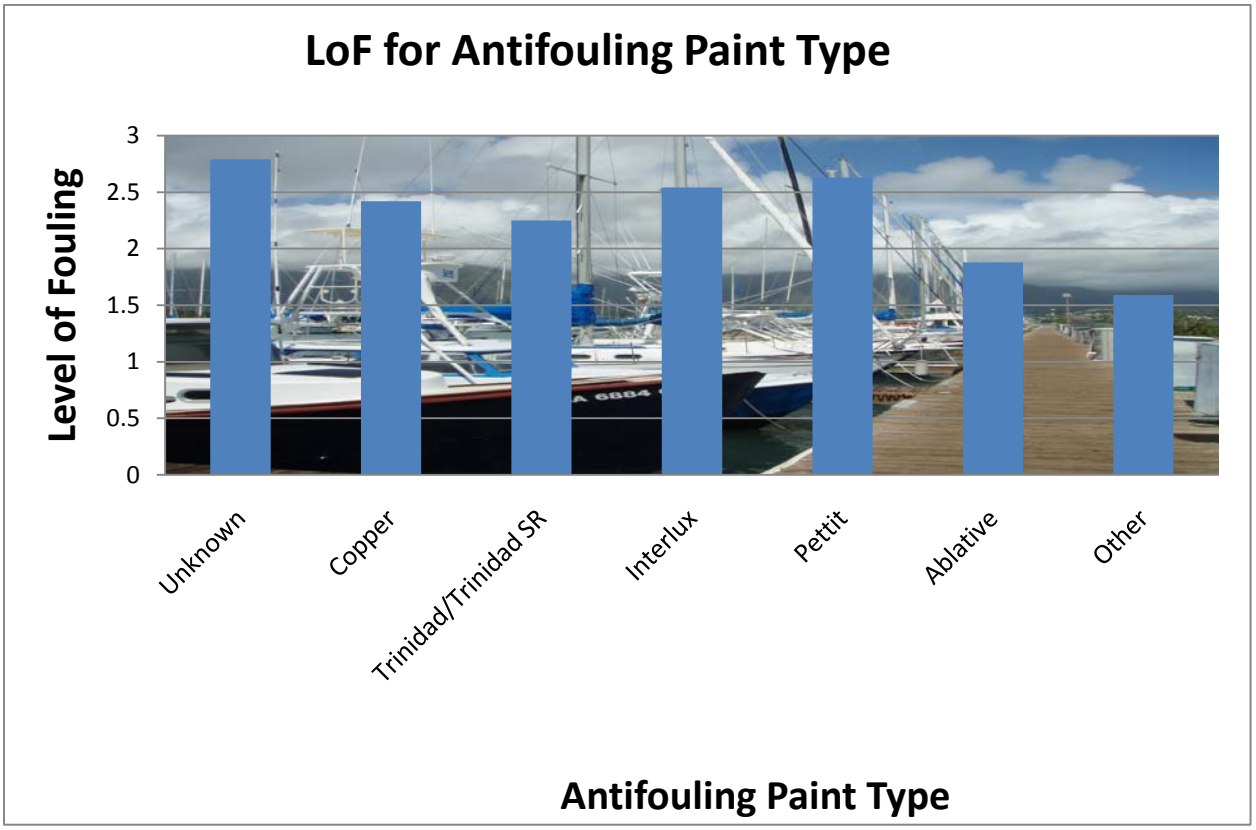
seems to be that the larger the vessel the less fouling. Also, motorboats had a lower LoF than sailboats. Many factors could contribute to these trends, including speed of a vessel, which should be researched further.

Most vessel owners and operators had reservations or were very guarded in answering questions or filling out the survey until they were told about the scope of the survey and that the information was for scientific use only. It was a good opportunity for outreach in which the problems of aquatic invasive species in Hawaii and best management practices to reduce the spread of these species took place. Owners and operators of vessels that were neglected and had high levels of fouling were very reluctant to participate in the survey. This gives the indication that the questionnaires answered and survey that were conducted were mostly on vessels were that were better maintained.

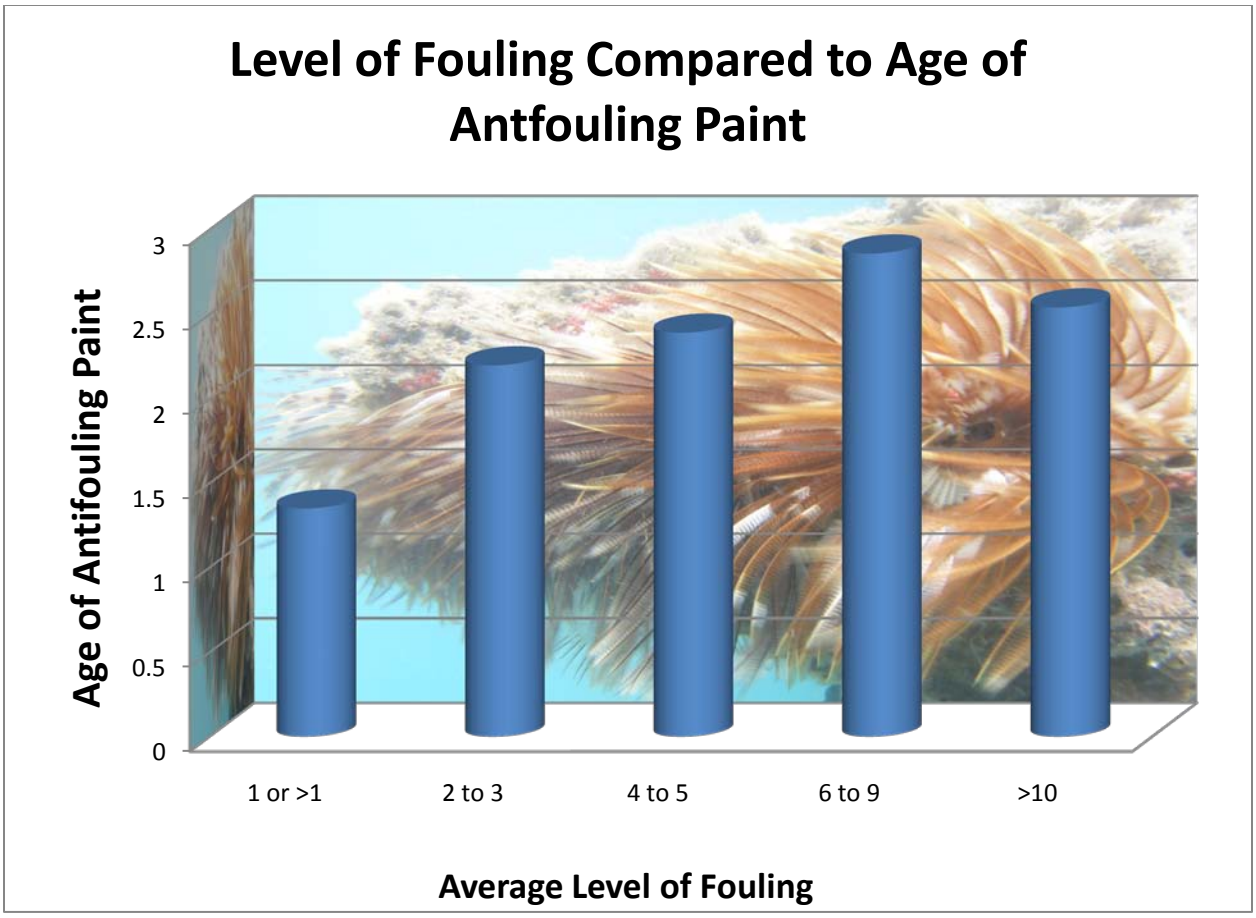
Survey results indicated that husbandry practices are being conducted regularly with a majority of the vessels being cleaned once or twice a year. A large number also indicated cleanings between three to six times a year. A small percentage cleaned on a monthly basis while some clean every 18 to 24 months. Most clean their vessels in harbor but a percentage clean their vessel in-water else were. This could be a problem if they are anchoring on the reef and possibly spreading the invasive species were there previously were none. The effects of in-water cleaning and transfer of invasive species not clearly understood (Hopkins and Forrest 2008). Research into this topic and balancing its effects and benefits needs to be better understood. Adopting best management practices or regulations to limit in-water cleaning may be necessary to reduce the risk of introducing species.

Survey showed that 73% of vessels have had antifouling paint applied within the last 5 years with the majority having done within two to three years and 27% of vessels have antifouling paint older than 5 years. Application of antifouling paint requires that vessels be hauled out, hull cleaned and dried prior to application of the paint. This is usually considered a decontamination of the vessel and the greatest way to reduce the risk of invasive species. Study of dynamics and length of antifouling paint effectiveness for recreational vessels should be looked at with greater detail. Of those who knew what type of antifouling paint was used Trinidad and Trinidad SR were the most popular. Trinidad SR Antifouling Paint users were the most enthusiastic about their paint saying that they tried others but that this was the best or that it is made for Hawaii and contained the most cuprous oxide . Check of West Marine showed it had the highest cuprous oxide at 70% plus dual biocide. It was also the most expensive at 229 per gallon, on sale, being more than twice the cost of some other types of bottom paints. Store staff confirmed that it was by far the most popular antifouling paint they

sold. Several vessel owners mentioned that they tried ablative antifouling that is designed to wear away with boat use, but changed back to paints with more cuprous oxide. Though owners and operators swore by this product, small sampling showed that other answers such as Americote, Marine and ablative showed a lower LoF.



When comparing age of antifouling paint found that the LoF increased with age of the paint. This characteristic has been noted in several studies as a reliable indicator of for introduction of invasive species (Ashton et al.,2006; Floerl and Inglis, 2001). Normal code of practice for commercial vessels is dry-docking and a reapplication of antifouling paint every 5 years.



The small sampling of vessels showed that those coming from the West had a higher degree of fouling. However, this may not be a good indicator as travel patterns for incoming vessel are complex (Goodwin and Eldredge 2004). Vessel grounding that was investigated by the AIS team sailed from Washington State to Mexico, then to the Marquesas, then finally Hawaii. Home marina is not a good indicator of where a vessel is from and questioner did not adequately address the complex travel patterns that exist. The potential that vessels from similar warm tropical region are a greater threat than vessels coming from temperate or cold water regions should be looked at in greater detail.

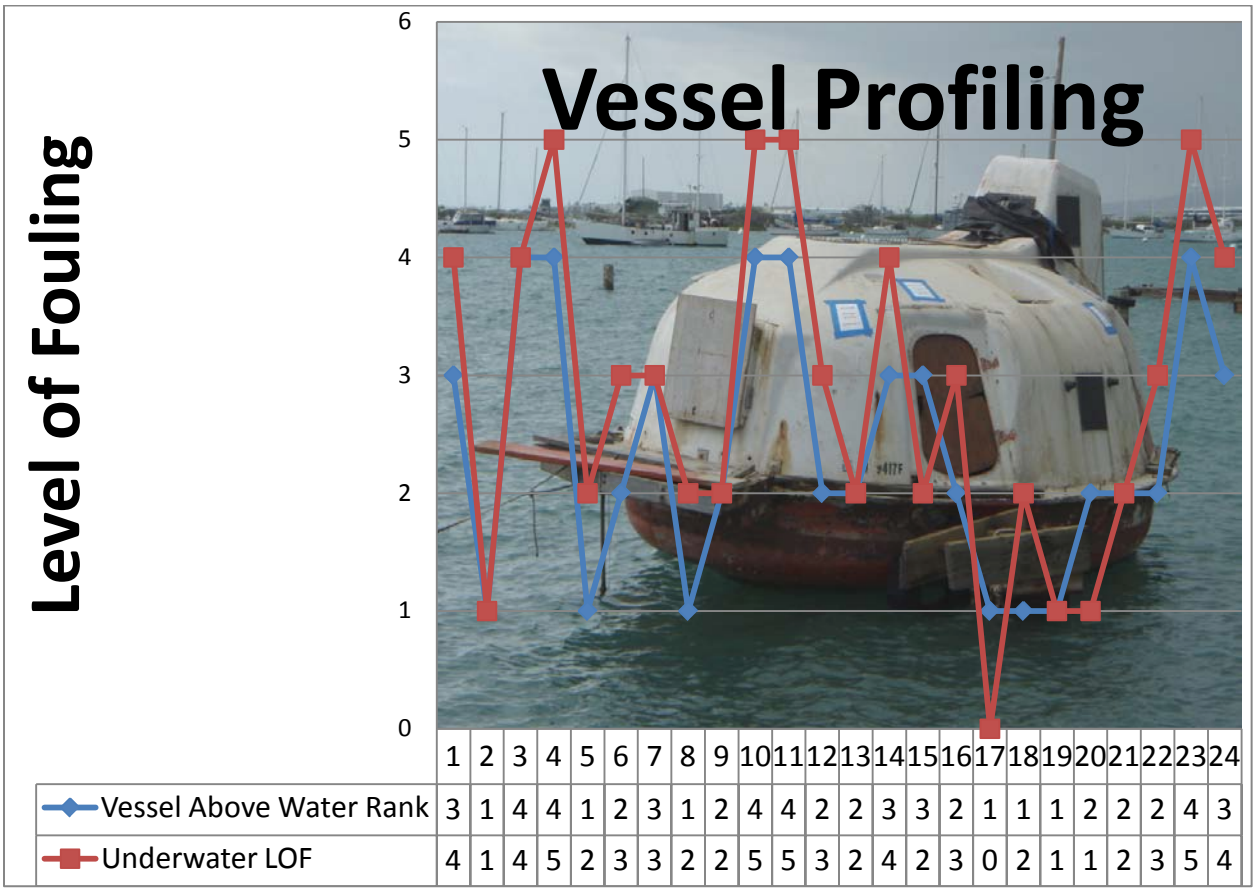
Study done on the East Coast, showed in preliminary observation, that there was a poor correlation between the level of fouling observed from the surface and from underwater inspections (Whitlatch, 2007). However other studies, including this one, found that this above water level of fouling can act as an indicator to what the actual level of fouling is (Floerl et al. 2005,Davidson et al. 2008). Hull surveys showed that above water LoF grading system can be used as a convenient management tool. Although the actual fouling was almost always higher than the above water grading, a strong correlation for matching up was shown. It can be used as a way to estimate the actual level of fouling

and pinpoint high risk vessels without having to enter the water or using any type of specialized equipment.

The study tried to differentiate difference between commercial and recreational vessels but difficult to distinguish, Honokohau at time of survey had 270 slips and 203 were surveyed as recreational vessels. Interviews with harbor agents revealed that 119 were commercial and 151 were recreational. It was also noted that many of the commercial vessels were used as recreational part of the time by owners. The data from Port Allen and Kewalo Basin were also removed because the majority of vessels there were commercial. LoF samples of 10 large commercial vessels, during other inspections for the state, reviled the same average of two. One vessel was overdue for dry-docking and had not had its hull cleaned in five years, except for propeller polishing but Lof was only two. Crew speculated that low LoF was because vessel is always moving and never spends more than 24 hours in port and high quality anti fouling paint is used.

Survey of biofouling showed that Slime was the most common group present followed by Macro algae, tubeworms, micro algae, barnacles and then bryozoans. San Francisco study showed that slime / biofilm was the most widely occurring fouling category followed by green algae, and bryozoans (Davidson et al. 2008). Tunicates and sponges were also common. Preliminary data for a study on the West Coast found that barnacles, bryozoans, gastropods and polychaete worms were the most common (Whitlatch et al. 2007). Hawaii study showed that barnacles were the most encountered group for overseas personal crafts arriving to Hawaii and for commercial barges, macro-algae, barnacles and mollusks were the dominate organism found (Godwin and Eldredge 2001). Wide ranges of groups were present in this study but for macro fouling algae, tubeworms and barnacles were the most abundant groups found. Level of fouling by position showed a trend that fouling increased as you go from bow to stern. Running gear also had the highest level of fouling. This is consistent with other studies that show niche areas to have higher level of fouling (Godwin at el. 2004, Whitlatch et al. 2007, Davidson et al. 2009).

Members of the AAOTF brought up the idea that neglected vessel pose high risk as being vectors or that a messy or unmaintained vessel would also have an unmaintained or messy bottom. Study of commercial ship arrivals in Hawaii showed that vessels that were poorly maintained were the most heavily fouled (Godwin and Eldridge 2001). This study found a very good correlation to the general up keep or maintenance of a vessel to the level of fouling observed on the underside of the vessel. A generalization of this would be well maintained vessels have low fouling, and neglected or unmaintained vessels have high fouling levels. This vessel profiling could be a used as a good tool to identify heavily fouled vessels. Data also showed that technique was effective at a distance using the optics of binoculars or a spotting scope.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Vessel Above Water Rank	3	1	4	4	1	2	3	1	2	4	4	2	2	3	3	2	1	1	1	2	2	2	4	3
Underwater LOF	4	1	4	5	2	3	3	2	2	5	5	3	2	4	2	3	0	2	1	1	2	3	5	4

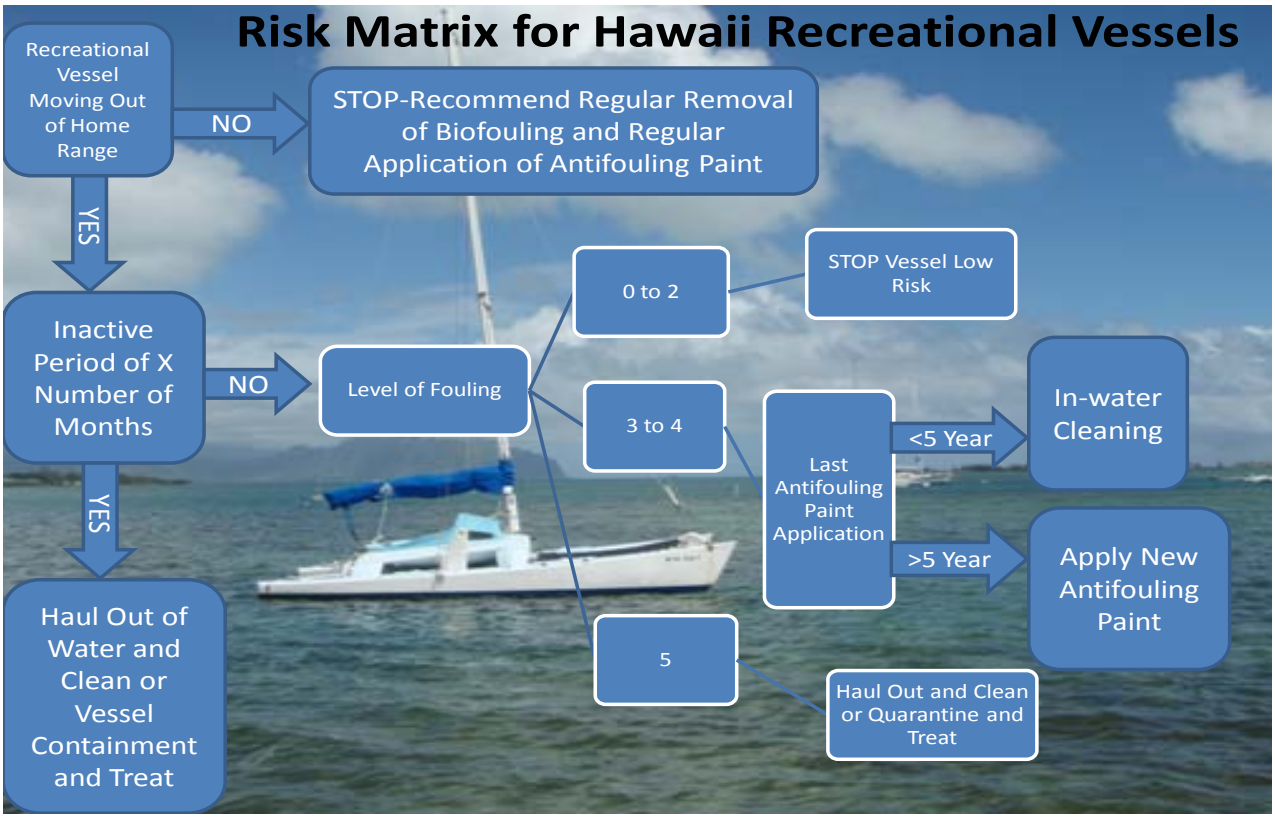
With the varied level of fouling and the discovery of alien species recreational vessel groundings could be a high risk to the transfer of invasive species to Hawaii.
The grounding and resulting scars are a good example of potential vectors for alien species' introduction to Hawaii. Before this study only commercial vessel groundings were monitored for aquatic invasive species. No direct transfer of alien species has been observed but established invasive algae would colonize the grounding scar and a recent grounding caused an algae bloom. Higher priority will be given to investigating recreational vessel groundings for aquatic invasive species and scars and surrounding

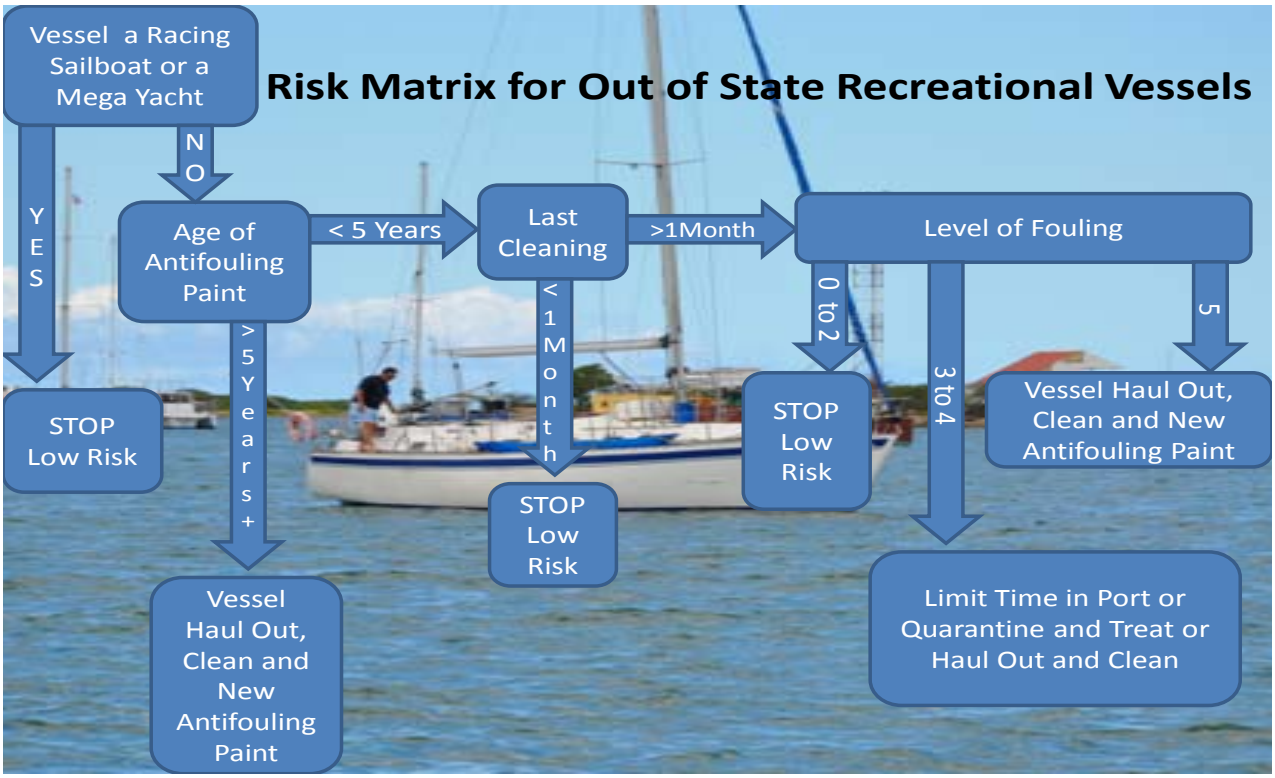
reefs will be further monitored in to determine if any of these alien species were able to colonize the reef.

A risk matrix is a series of decisions based on a vessels level of fouling, hull husbandry and travel history that could be used to potentially pinpoint high risk vessels (Godwin, 2004). Although it is possible that introductions could occur from low fouled vessels or other factors not know, risk assessment tools can be used for management efforts (Acosta and Forrest, 2009). Two risk matrixes were developed, one for Hawaii and one for out of state recreational vessels. They were based on a risk matrix developed by Scott Godwin and Hawaii's AAOTF and incorporating components that were learned in this project. Ideas that were factored into the matrixes:

1. The potential for introduction of aquatic invasive species should be increase by the level of fouling on a vessel (Floral at el. 2005).
2. Study on yacht hulls in New Zealand and Scotland found that the age of the anti-fouling paint was the most important factor risk factors (Ashton et al.,2006; Floerl and Inglis, 2001).
3. Type of Vessel could affect risk.
4. Hull husbandry practices play a role in LoF.

Ending actions of the matrixes include stop or no action because low risk, limit time in port, quarantine and treat, haul out and clean and apply new antifouling paint. Risk matrixes are not a final product but rather an evolving management tool that can be refined and improved as more work is done to address this vector and more research is done.


Risk Matrix for Hawaii Recreational Vessels
Recreational Vessel Moving Out of Home Range
NO
STOP-Recommend Regular Removal of Biofouling and Regular Application of Antifouling Paint
YES
Inactive Period of X Number of Months
NO
Level of Fouling
0 to 2
STOP Vessel Low Risk
3 to 4
Last Antifouling Paint Application
<5 Year
In-water Cleaning
>5 Year
Apply New Antifouling Paint
YES
Haul Out of Water and Clean or Vessel Containment and Treat
5
Haul Out and Clean or Quarantine and Treat


Vessel a Racing Sailboat or a Mega Yacht
Risk Matrix for Out of State Recreational Vessels
YES
NO
Age of Antifouling Paint
< 5 Years
Last Cleaning
>1Month
Level of Fouling
STOP Low Risk
>5 Years+
< 1 Month
0 to 2
3 to 4
5
STOP Low Risk
STOP Low Risk
Vessel Haul Out, Clean and New Antifouling Paint
Vessel Haul Out, Clean and New Antifouling Paint
Limit Time in Port or Quarantine and Treat or Haul Out and Clean

To properly address this vector, strong practical regulations need to be adopted, on a state level, to manage and deal with recreational vessels. For now need to continue to work with recreational boating community with outreach, apply best management practices, encourage behaviors that prevent fouling and addressing high risk vessels on a case by case basis. Strategies such as the vessel wrapping system, limiting time in port or requesting a haul out and cleaning at an appropriate facility can be used to lower the risk of vessels. Protection of our Borders from terrestrial invasive species is handled by two agencies; The Hawaii Department of Agriculture which inspects domestic cargo and vessels and the federal Department of Homeland Security Customs and Border Protection are responsible for inspection of foreign cargo and vessels. Regulations require that vessels arriving from foreign ports must call to an official port of entry before proceeding elsewhere in the state. Working with these agencies, harbor agents and others in the boating community would be important, especially at points of entry, to pinpoint high risk vessel. A general lack of awareness of the problems of aquatic invasive species by vessel owners and operators, harbor personnel and general public was observed throughout this project. Outreach became an important priority and information about the threat of aquatic invasive species and practices to minimize the spread were given.

If regulations are adopted for mandatory cleaning of highly fouled vessels, appropriate decontamination areas need to be developed. Research into the feasibility of building a decontamination area for vessels revealed that it would be a very large task and at much expense. Currently a majority of the vessels do in-water cleaning which may pose a risk to the spread of AIS but there are many factors involved and more study needs to be done for the risk posed (Hopkins and Forrest, 2008) It is believed that the potential to introduce invasive species is increased by in-water cleaning. This type of cleaning should only be done if an containment system could be used to retain the hull fouling (Godwin et al. 2004, Godwin 2005) A prototype vessel wrapping system that was being tested and developed in Australia was looked at and tested a practical solution to quarantine and decontaminates high risk vessels (Derek and Coutts 2009). Australia has seen the effects of aquatic invasive species and has taken major steps in protecting its aquatic resources. Currently they have regulations for recreational vessels under 25m in which they are required to show proof that they had anti-fouling paint applied within a year or had hull cleaned within a month or that vessel be hauled out and cleaned within a week of arrival. The IMProtector or Introduced Marine Pest Protector was created as a practical tool to assist mangers in addressing high risk vessels. It is used while a vessel is still in the water by surrounding vessel with the system and pumping the water out. This causes an anaerobic condition and kills the

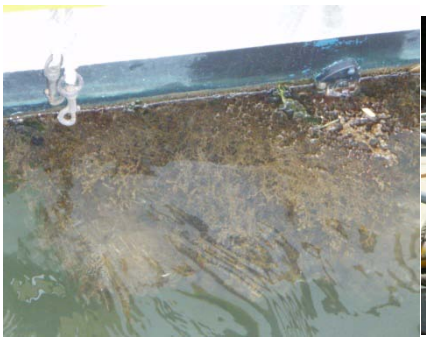
biofouling. System was tested on Division's 26' Boston Whaler and provided for an effective way to quarantine a vessel and provided for an anaerobic condition to occur. The system is basically a PVC bag with built in flotation device, using a smaller vessel it was pulled under the target vessel and the end was zipped up and secured to the sides. Two Honda WX15 lightweight water pumps with a 72 gal/ min capacity were used to removing the extra water. System was easy to deploy and take down, requiring less than an hour for each procedure and caused no harm to the vessel. The potential to use this product in Hawaii is very good. Currently, will have to work with owners and operators on a voluntary basis. The need for proper legislation on hull fouling is needed so that appropriate vessels can be addressed to protect Hawaii's aquatic resources. System is being looked at as a tool for the Papahanaumokuakea Marine National Monument, which occasionally gets recreational vessel arrivals and there is great concern for invasive species introduction into its pristine environment.

Research is being conducted by Division's AIS Research Specialist on chemicals or pesticides that could speed up the process of killing the biofouling organisms in this closed system. Hydrated lime, chlorine, citric acid and acetic acid look promising and would improve the effectiveness of the system. Regulatory restrictions and worry about the environment could limit the use of chemicals in Hawaii (Tavares-Reager 2009). However the system is closed and remaining solution can be pumped into a containment tank so use maybe possible.






Pressure washer was also tested to see its usefulness as to decontaminate a hauled out vessel. Preliminary tests showed it to be effective in removing most of the visible fouling on lightly fouled boats. Decontamination protocols for freshwater mussels on water craft recommends the uses of 140 degree Fahrenheit or hotter at the point of contact with the pressure washer along with a drying time or waiting period (Zook and Phillips 2009). Division recently acquired a hot water pressure sprayer for aquatic invasive species eradication underwater, it has yet to be tested for hull fouling. Should be effective on marine hull fouling organisms but have to manage for possible damage it could cause to a vessel. Disposal issues also need to be looked at for dead aquatic mater.


Many other components of recreational hull fouling as a vector for the introduction of aquatic invasive species need to be looked at in the future:
1. Investigating non hull sources of AIS introductions from recreational vessels, including bilge water, anchors, chains, water inlets and outlets and other parts and equipment in contact with sea water.
2. Vessels arriving into the state as cargo aboard larger vessels.
3. Freshwater component especially important with the movement of zebra and quagga mussels. West Coast States have initiated very strict rules and decontamination measures to reduce the movement of them (Zook and Phillips 2009).
4. Look at niche spots on the hull.
5. In-depth look into species level, vessel speed, residency time, season, vessel type,

Hull fouling by recreational vessels as a vector for transmission of aquatic invasive species is poorly understood and much more research needs to be done. Conducting this study has let more questions opened and more issues to address. However study has increased knowledge of recreational hull fouling in Hawaii, developed management tools that can be used and the capacity of the State to deal with this vector has been increased.

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