Impacts to Wildlife and Natural Resources from Personal Watercraft

A Literature Review
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I. INTRODUCTION

A. Purpose of this Report:

In response to public interest, the Alaska Department of Fish and Game (ADF&G) and Alaska Department of Natural Resources (ADNR) conducted public meetings and solicited public comments concerning the use of personal watercraft (PWC) in the Kachemak Bay and Fox River Flats critical habitat area (CHAs). In conjunction with seeking public input, the ADF&G conducted a review of literature relevant to the use of PWC and their potential impacts to natural resources including fish, wildlife, and air and water quality. While not the focus of this literature review, a brief summary of materials on PWC safety and operator injuries is also included.

B. Scope and Summary of Literature Review:

Sources of reviewed information include scientific and popular publications; federal, state and local agency management documents and staff reports; publications and reports from private organizations; and statement and testimony from biological and physical scientists and resource managers. While this literature search attempted to review a broad range of available materials, it is not intended to be exhaustive or all-inclusive. To document the extent of this review, a bibliography of reviewed material is attached, although not all sources are cited in the narrative of this report.

Few dedicated studies that investigated the impacts of PWC to fish, wildlife, and other biological resources, and to air and water quality exist. The majority of the available literature examines disturbances to these resources from human activities including, but not limited to: conventional motorboats, two- and four-stroke outboard boat engines, aircraft, land-based activities such as motor vehicles, and recreational activities such as bird watching and fishing. Boating-related activities have been found to impact natural resources by affecting: water turbulence and turbidity; bank erosion; cutting of vegetation by propellers; direct contact with river banks and riparian vegetation; direct collisions with wildlife; visual and auditory disturbances to wildlife; impacts to bird nests, eggs, and nestlings; and air and water pollution from motors and sewage. Pomerantz et al. (1988) classified these impacts to wildlife in six categories and includes 1) direct mortality, 2) indirect mortality, 3) lowered productivity, 4) reduced use of preferred habitat, 5) aberrant behavior, and 6) stress. While this literature review primarily presents a summary of the impacts caused by all boating activities, rather than those isolated to PWC, it should prove useful in determining whether the use of PWC represents a unique impact to the natural resources of the Kachemak Bay and Fox River Flats CHAs.

II. DIRECT IMPACTS TO WILDLIFE:

A. General Impacts to Wildlife:

While numerous publications exist that describe the direct impacts of boats and other human activities on wildlife (including birds, marine mammals, crocodiles, fish and other aquatic life forms), only two dedicated studies have explored whether differences exist between the impacts created from the use of traditional outboard motorboats and those from PWC. In abundance are studies on the human impacts to breeding birds, particularly colonial nesting water birds. Impacts from various human disturbance on wildlife, including those from watercraft, have been described by researchers and include such affects as reducing productivity, affecting foraging behavior, abandonment of breeding territories, altering distribution, and increasing predation (e.g. Knight 1986, Anderson 1988, Bratton 1990, Mikola et al. 1994). As an example, studies on double-crested cormorants (*Phalacrocorax auritus*) in Maine and king shags (*Phalacrocorax albiventer*) in Argentina reveled that human disturbance in the nesting colony not only increases the vulnerability of eggs and chicks to predation by gulls, but also causes the adults to regurgitate fish (Kurby 1975). This regurgitation provides an alternate food item for the gulls, thereby decreasing predation on their eggs and chicks. The author surmised that repeated human disturbance could harm growing young by depriving them of food.

B. Personal Watercraft Studies:

Two studies that specifically examined PWC recorded somewhat conflicting findings. Rodgers (1999) exposed 39 species of loafing or feeding waterbirds (Pelecaniformes, Ciconiiformes, Falconiformes and Charadriiformes) in Florida to the rapid approach of a PWC and an outboard-powered boat to determine their flushing distances to these two watercraft. While 11 species showed no significant difference in flush distance, five species (anhinga (*Anhinga anhinga*), little blue heron (*Egretta caerulea*), caspian tern (*Sterna caspia*), willet (*Catoptrophorus semipalmatus*), and osprey (*Pandion haliaetus*)) exhibited significantly larger flush distances to the approach of the outboard-powered boat. Only one species (great blue heron (*Ardea herodias*)) exhibited a significantly larger flush distance to the approach of a PWC. The author suggests that his preliminary data indicate that a single buffer zone distance should be applied to both types of watercraft. However, another study at a nesting colony of common terns (*Sterna hirundo*) along the coast of New Jersey found that significantly more birds were off their nests and circling the colony when a passing watercraft was a PWC, rather than a conventional motorboat (Burger 1998). This study also reported that a significantly larger number of birds were in flight over the colony the closer a watercraft passed to the colony and the faster the speed of the watercraft.

Biologists working in the Ten Thousand Islands region of Florida's Everglades are currently proposing to conduct a study comparing the impacts of PWC, outboard motorboats, canoes/kayaks, and airboats on foraging and loafing waterbirds, particularly shorebirds which were not represented well in these other studies (Hopkins and Doyle 1999). They propose to operate the craft in several configurations including single and multiple vessels using both direct and S-curve approaches.

C. Buffer Zones and Differences in Types of Disturbance:

Many of the published studies on disturbances to wildlife attempt to quantify recommended setbacks which human activities should maintain from birds, particularly breeding colonies of waterbirds. As previously mentioned, few dedicated studies investigated the impacts from PWC but some general conclusions may be drawn from studies that did compare various disturbance types. These appear to be related to the predictability, linear movement, and speed of the disturbance.

Rodgers and Smith (1995) studied fifteen species of nesting colonial waterbirds (Pelecaniformes, Ciconiiformes and Charadriiformes) in Florida and exposed them to three types of human disturbances (walking, motorboat, and canoe). Their results generally show that these waterbirds exhibited a greater flush distance in reaction to a walking approach rather than a motorboat approach. Their data set for disturbances from canoes was too limited to draw many conclusions; however, anhingas flushed at a distance similar to that of a motorboat. Therefore, they recommend the same setback distances for preventing disturbance to nesting colonial birds for both types of vessels. While they observed both interspecific and intraspecific variations in flushing responses to the same human disturbance, the authors recommended a set-back distance of about 100 meters for wading colonial birds and 180 meters for mixed tern/skimmer colonies. Similarly, Erwin (1989) recommended buffers of up to 200 meters to prevent disturbance to wading birds and seabirds based on his research at coastal sites in Virginia and North Carolina.

In a separate study designed to establish recommended buffer zones from feeding and loafing birds, Rodgers and Smith (1997) exposed 16 species of non-nesting waterbirds (Pelecaniformes, Ciconiiformes and Charadriiformes) to four types of human disturbances (walking, all-terrain vehicle, motor vehicle, and motorboat). While most species did not exhibit a significant difference between the four disturbance types, some species did exhibit a significant difference between automobile and all-terrain vehicle approaches. While both interspecific and intraspecific variations were observed in flushing responses to the same human disturbance, the authors recommended a setback distance of about 100 meters to minimize disturbance to most species of waterbirds that they studied.

Researchers working in New York's Jamaica Bay National Wildlife Refuge determined that land-based human activity nearly always had a disturbance to waterbirds in the refuge but that faster moving activities (joggers) disturbed birds significantly more than slow moving bird watchers (Burger 1981). Fraser (1987) found that common eiders along the coast of South Africa usually ignored the approach of dinghies, small sailboats, and engine-powered boats; however, the rapid approach of a windsurfer caused widespread panic among the flock. Jahn and Hunt (1964) studied boating disturbances to waterbirds in Wisconsin and speculated that airboats pose a serious threat to waterfowl productivity in Wisconsin due to their ability to invade shallow-water areas of most value to these birds. Other researchers in Scotland found that shore-based activities such as people fishing or walking and dogs, caused more disturbance to common eider ducklings than did water-based disturbances such as windsurfers and rowboats (Keller 1991).

D. Impacts to Fish:

Some studies have investigated the impacts of motorboats to fish species including the affects of jet-driven motorboats on salmon reproduction (Horton 1994). This study at American Creek on the Alaska Peninsula determined that the discharge from the jet unit resulted in a significant mortality of salmon eggs. Embryos were killed either in the gravel by the impact of the jet discharge (63% mortality) in water depths of 13-23 cm (5-9 inches) or as a result of being displaced from the gravel (up to 100% mortality). In a laboratory setting, Reynolds' results indicate that pressure waves from boats was not a contributing factor to embryo mortality. Anecdotal observations from Everglades National Park report that fishing success dropped to zero when PWC were used in the same waters and that recovery time was reported to be 1-2 hours; however, the author did not provide information on the suspected reason for the impact to fishing success (Snow 1989).

E. Observations and Opinions of Professionals:

1. General Observations/Opinions:

In addition to the studies cited above, there is considerable anecdotal information on PWC, including the opinions and testimony of biologists, refuge managers, park rangers and other professionals. Some have indicated that PWC pose a greater potential threat to wildlife than do conventional motorboats. They cite the higher noise levels, faster speeds, erratic movements, the PWC's ability to enter shallower water, and their tendency to operate in groups as reasons why PWC impact wildlife to a greater degree than other boats. While these observations were detailed in several management and agency documents, they are difficult to show definitively without further research and are provided here to add to the understanding of the potential impacts to the resources of the Kachemak Bay and Fox River Flats CHAs.

Everglades National Park in Florida has been concerned about the potential impacts of PWC on park wildlife and resources for at least the past 12 years. The park's Natural Resource Management Specialist has categorized the potential environmental disruptions from PWC on park resources as noise, human intrusion, alteration of vegetation, and emissions of harmful substances (Snow 1989). However, he also states that these disruptions and their related impacts are shared by both PWC and conventional motorboats and suggests that a prohibition on PWC in the park should also be accompanied by a review of the impacts from conventional motorboats and the adaptation of appropriate restrictions. Snow identifies significant differences in the operation of PWC compared to conventional motorboats and includes the tendency of PWC to make repeated passes in a localized area, that they are highly maneuverable, can constantly change direction making them unpredictable, that they often travel in groups, and that they can travel faster when closer to shore. He concludes that these types of watercraft operations may result in significantly more disturbance to wildlife and resources than the types of operations of conventional motorboats.

2. Noise Impacts:

Snow acknowledges that resource and recreation managers generally agree that the noise from a PWC is actually less than a conventional motorboat when operated on open water, but because PWC travel faster and are operated closer to shore, they are perceived as being noisier. However, since PWC are often operated in groups, and may make several passes in the same area, the cumulative impacts of their noise may be higher than conventional motorboats. Snow states that the literature supports the notion that most physiological systems can be influenced by noise and numerous behavioral studies have documented a "startle response" in wildlife. The noise associated with PWC may be more significant than that generated by conventional motorboats because of their repeated operation in a localized area. Adverse impacts from noise may include the interruption of activity; alarm and flight; avoidance and displacement; interference with movement and predator-prey relationships; and interference with courtship.

In a report prepared for Washington's San Juan County Board of Supervisors, the authors quote a biologist with The Whale Museum on San Juan Island concerning a study conducted by the Woods Hole Oceanographic Institute (Aquatic Resour. Conserv. Group 1998). This study indicated that PWC were much quieter underwater than any of the motorboats tested. The report states that PWC generated a high frequency noise that did not travel far supporting the notion that PWC were more likely to startle marine mammals than an outboard vessel because PWC cannot be heard as far away as most other boats. The report also quotes a marine mammal research biologist with the National Oceanic and Atmospheric Administration as stating "jet skis are designed to be highly maneuverable and to accelerate quickly, which leads them to be operated with frequent course and speed changes. The unpredictability of these sounds is probably more adversive than any single feature of the sound, such as its frequency or absolute level". The report states that further scientific investigations are necessary to make more definite conclusions about the effects of PWC noise on marine mammals; however, they state that in addition to the unpredictability of PWC and the fact that PWC often operate in groups, it makes it more difficult for marine mammals to find safe escape routes and breathing spots. Additionally, since PWC typically operate in a given location for prolonged periods, the duration of the exposure to the disturbance of a PWC is typically longer than that from outboard motorboats.

The San Juan report also quotes a biologist studying marbled murrelets (*Brachyramphus marmoratus*) in the San Juan Islands and relates anecdotal evidence supporting the idea that PWC comprise a unique disturbance. He observed three interactions between PWC and murrelets and in each case, the birds flew from the area where they had been feeding. He stated that this was unusual behavior as murrelets usually respond to motorboats by diving and respond with flight in only approximately 5% of the cases. This biologist theorizes that the loud noise of the PWC may cause more of a fear response; however, he cautioned that the paucity of his observations make this a tentative conclusion.

3. Human Intrusion Impacts:

The wildlife impacts from human intrusion and PWC traffic are similar to the impacts from noise (interruption of activity; alarm and flight; avoidance and displacement; interference with movement and predator-prey relationships; and interference with courtship) but may also include the permanent loss of habitat; decreased reproductive success; interference with movement; direct mortality; and alteration of behavior (Snow 1989). Some resource managers have observed that collisions between wildlife and PWC are more likely because of the operator's limited visibility and because the highly maneuverable PWC is more confusing to fleeing wildlife than a conventional motorboat. In a report prepared for Washington's San Juan County Board of Supervisors, the authors provided several examples of disturbances to marine mammals by approaching boats (Aquatic Resour. Conserv. Group 1989). The report also quoted a biologist with The Whale Museum who believes PWC pose a substantial threat to marine mammals due to the typical operation of PWC at high speeds, erratic paths, travel in groups, and their entry into areas not accessible to most other boats. These authors go on to say that marine mammals and other wildlife can respond in several ways to disturbance from watercraft including using alternate habitats if available, habituation, and sensitization. However, they cite several biologists who state that animals are less likely to habituate to a highly variable stimulus, such as a constantly changing noise or highly maneuverable object, than to a steady stimulus. One source felt that marine birds and mammals would never be able to habituate to, or adapt to this characteristic of PWC.

The authors of the San Juan report also provide anecdotal observations of a biologist from the Cypress Grove Preserve in California who stated that he has observed shorebirds and waterbirds that were more easily disturbed by changes in speed and direction (such as those from a PWC) than by movement at a steady moderate speed in a constant direction (such as those from a motorboat). He also added that an abrupt reduction in speed can flush a flock from a roost area as easily as quick acceleration.

4. Vegetation Impacts:

Boating impacts to vegetation have been summarized as the permanent loss of habitat and a change in community structure (Snow 1989). While Snow attributes little damage to seagrass beds and other bottom vegetation to PWC use, he states that they are capable of damaging emergent vegetation more than conventional motorboats given their ability to run faster in shallower nearshore waters. Like conventional motorboats, PWC can also increase turbidity and probably redistribute benthic invertebrates. However, PWC may prolong these impacts because of repeated use by multiple machines in a limited area.

III. AIR AND WATER QUALITY IMPACTS:

A. Background:

VanMouwerik and Hagemann (1999) provide a general summary of the pollutants discharged from two-stroke engines. These include BTEX (benzene, toluene, ethyl benzene and xylene) and

MTBE (metyl-tertiary-butyl-ether) which are discharged to receiving waters from unburned fuel; and PAHs (polycyclic aromatic hydrocarbons) which are discharged in small quantities from unburned fuel and in much larger amounts as part of the engine's exhaust. A conventional two-stroke engine expels as much as 30% of the incoming fuel mixture, unburned, via the exhaust. Newer two-stroke engines (including those used on some new model PWC) reduce, by up to four-fold, the amount of smog-forming pollution discharged through the exhaust. However, emissions from these newer models are still four times that of four-stroke engines of the same horsepower. Under new U.S. Environmental Protection Agency (USEPA) regulations, new typical marine engines (PWC, outboards, and jet-boats) are required to reduce exhaust hydrocarbon emissions over the next several years with full implementation by 2025 when a 75% reduction is mandatory. California's Air Resources Board regulations adopted similar regulations with earlier deadlines and emissions will become 75% cleaner by 2001 and 90% cleaner by 2008. It is expected that most manufactures in the U.S. market will offer a full range of these newer two-stroke engines on their PWC by approximately 2002.

B. Impacts to Resources:

Several researchers have examined the relationship between boating activity, the presence of contaminants, and the impacts that these contaminants have on aquatic resources. Examples include Oris et al. (1998) who found that peak boating activity in California's Lake Tahoe corresponded with higher levels of PAHs. Results from their work provided evidence that ambient levels of exhaust components (PAHs) from motorized watercraft caused photo-activated (i.e. ultraviolet radiation) toxicity to fathead minnows (*Pimephales promelas*) (a 46% decrease in larval growth) and zooplankton (*Ceriodaphnia dubia*) (mortality) as well as direct toxicity (mortality) to the zooplankton. Studies of the physiological impacts from two-cycle outboard motor exhausts on teleost fish in a controlled setting, mimicked the exhaust levels which might be found in field situations (Tjärnlund et al. 1995, 1996). These studies found toxicological effects that have been measured in the genetic material in the liver, kidney and blood; enzymatic disturbances in the liver; carbohydrate metabolism; and reproductive disturbances such as toxicity to early life stages of the fish. Another study found differences in physiological impacts from two-stroke engine emissions based on the fish's gender (Ericson 1997).

Others have concluded that residual polycyclic hydrocarbons (PHs) in water from outboard motors can be toxic to zooplankton (Giesy 1997). Giesy's testimony before the Tahoe Regional Planning Agency cites laboratory studies that reported two-stroke effluent from outboard motors was acutely toxic to zooplankton even when diluted by a factor of 32. The effluent caused 100% mortality of the zooplankton in 7 days when diluted by a factor of 128. Giesy surmises that the true toxicity of some components of two-stroke engine exhaust are as much as 50,000 times as toxic under field conditions in the presence of ultraviolet (UV) light from sunlight. He further stated that this could significantly alter the community structures of phytoplankton and zooplankton, the base of the aquatic foodchain, which in turn could have severe effects on fish populations. Additionally, eggs or fry of some fish species in the littoral zone, where exposure to greater concentrations of UV light as well as more PAH, could be directly affected.

On the other hand, studies by several researchers indicated that MTBEs (a gasoline oxygenate additive), while classified as a possible human carcinogen by the USEPA, apparently have little known toxicity to aquatic organisms (Johnson 1998, Werner and Hinton 1998). Additionally, MTBEs do not appear to be a significant bioaccumulate in the food chain and it does not readily adsorb or bind to organic particles (Tahoe Res. Group 1997). These and most studies (e.g. Reuter 1998) which investigated the presence and impacts of MTBEs attribute the presence of this pollutant to two-stroke watercraft exhaust. The majority of these studies were conducted in freshwater lakes and no literature was available on studies conducted in marine environments.

A literature review by the USEPA, Engine and Motor Vehicle Branch of 11 papers dealing with the impacts of marine engine exhaust emissions on water quality led to their determination that "several of the authors find that concentrated levels of marine engine exhaust emissions do have an impact on marine ecosystems. However, at the concentrations at which they actually occur, most researchers conclude that these effects are small and, in most cases, do not adversely affect most marine plants and animals" (Revelt 1994). This review further stated "the overall water quality effects of marine engine exhaust gases does not appear to be significant in general". The Tahoe Research Group (1997), a consortium of researchers from the University of California, Davis, investigating watercraft impacts to Lake Tahoe, summarized the available literature stating that "studies on the impacts of watercraft engine exhaust on aquatic life indicate that deleterious effects can occur both in terms of mortality and histopathological responses. However, good field research linking in-lake conditions to these impacts are generally lacking". Presumably in a marine environment with significantly more flushing action than a freshwater lake, these impacts would be even more difficult to identify.

C. <u>PWC/Outboard Motorboat Comparisons</u>:

The literature contains few studies that address the differences of impacts to air and water quality from PWC compared to traditional motorboats. While most studies investigated air and water quality impacts from two-stroke marine boat motors, Fiore et al. (1998) compared exhaust emissions from a PWC and two outboard motorboats in a field situation. Their study concluded that the emissions from the PWC discharged more MTBE, benzene, and xylenes than the two outboard motorboats used in the study and the PWC emissions were in excess of the drinking water standards established by the California Department of Health Services. However, the outboard motors in this study utilized newer technologies such as direct fuel injection and 4-stroke carburated engines while the PWC was a traditional 2-stroke carburated engine. Therefor, it would be inappropriate to use this study to make comparisons of emission levels based on watercraft type (i.e. PWC vs. conventional outboard). It would however, be appropriate to use this study to make emission comparisons based on engine type (i.e. fuel injection, 4-stroke, conventional 2-stroke).

VanMouwerik and Hagemann (1999) suggested that PWC use more fuel and discharge more pollution to the water than other watercraft with outboard two-stroke engines because they are designed and operated differently. PWC have a narrow hull that rides low or sinks in the water and in order to plane the hull, operators commonly open the throttle fully. Additionally, PWC tend to sink when performing common stunts at lower speeds and the throttle must be fully opened to complete the maneuver. A study in California found that although PWC account for only one-third of the watercraft used in the state, they emitted 80% of the hydrocarbons, 66% of the nitrogen oxides (NO_x), 78% of the carbon monoxide, and 76% of the particulate matter

(Calif. Env. Prot. Agency 1998a). In a report prepared for Washington's San Juan County Board of Supervisors, the authors quote an official with California's Air Resources Board as stating that "PWC, because of their use characteristics, are more polluting on average than 2-stroke engines used in vessels with outboard engines" (Aquatic Resour. Conserv. Group 1998). The reasoning for this statement was that "exhaust emissions are directly dependent on horsepower and load factor. Load factor means the fraction of full power typically used by an engine of a specific equipment type. PWC have sizable horsepower ratings, averaging 82 in 1987, and a load factor twice as high as outboard vessels. Vessels with outboards on average use 32% of their horsepower whereas PWC use 76%".

IV. SAFETY CONCERNS

While the overall number of recreational boating fatalities in the United States has been decreasing in recent years, fatalities from PWC have increased 220% from 1993 when 26 fatalities occurred to 1997 when 83 fatalities occurred (Nat. Transp. Safety Board 1998). Unlike other types of recreational vessels, the leading cause of death in PWC accidents is not drowning but is rather from blunt trauma.

Approximately 2,500 accidents involving PWC were reported to the National Transportation Safety Board in 1997 and the most prevalent types of accident were from vessel collisions (46%), falls overboard (11%) and collision with an object (8%). Inattention, inexperience, and inappropriate speed for the operating conditions were the most frequently cited causes for these accidents. In 1997, the NTSB received reports of 6 PWC accidents in Alaska with one fatality. This accounts for 6.6% of boating accidents in the state and 4.7% of boating fatalities in the state.

The annual number of injuries resulting from PWC use in the United States has increased approximately 330% between 1990 when U.S. hospitals reported 2,860 injuries to PWC operators and 1995 when 12,288 injuries were reported (Branche et al. 1997). This represents an 8.5-fold increase in the number of treated injuries over that for other motorized watercraft. The most prevalent diagnoses were lacerations, contusions, and fractures.

V. CONCLUSIONS

While numerous studies have investigated the impacts of boating and other human activities on fish, wildlife, and other natural resource, only two studies have specifically investigated the disturbances of personal watercraft. These two studies came to somewhat different conclusions. A study in Florida indicated that personal watercraft were not more disturbing to feeding and loafing waterbirds than were conventional motorboats; while work in New Jersey indicated that personal watercraft were more disruptive to a common tern nesting colony than were conventional motorboats.

Considerable anecdotal information on the impacts of personal watercraft exists. While personal watercraft do not appear to be inherently more disruptive to wildlife or more polluting than other 2-stroke marine engines, many professional biologists and managers point to the characteristics of their use which may make them more disruptive and polluting than conventional watercraft.

They cite the higher noise levels, faster speeds, erratic movements, the PWC's ability to enter shallower water, and their tendency to operate in groups as reasons why PWC impact wildlife to a greater degree than conventional motorboats.

BIBLIOGRAPHY OF REVIEWED LITERATURE

Anderson, D.W. 1988. Dose-response relationship between human disturbance and Brown Pelican breeding success. Wildl. Soc. Bull. 16:339-345.

Anderson, D.W., and J.O. Keith. 1980. The human influence on seabird nesting success: conservation implications. Biol. Conserv. 18:65-80.

Aquatic Resources Conservation Group. 1998. Personal watercraft use in the San Juan Islands. San Juan County Planning Dep., San Juan County, Wash. 86pp.

Ballestero, T. P. 1990. Impact of motor boat and personal water craft on the environment: bibliography. Environ. Res. Group, Univ. of N.H., Durham. 25pp.

Balk, L., G. Ericson, E. Lindesjöö, I. Petterson, U. Tjärnlund, and G. Akerman. 1994. Effects of exhaust from two-stroke outboard engines on fish – studies of genotoxic, enzymatic, physiological and histological disorders at the individual level. Inst. of Appl. Environ. Res., Lab. For Aquatic ecotoxicology, Stockholm Univ., Sweden. 70pp.

Bannan, M. 1997. The effects of powerboat emissions on the water quality of Loch Lomond, fourth year postgraduate annual report. Zool. Dept., Glasgow Univ. and Univ. Field Sta., Rowardennan, Scotland. 8pp.

Bouffard, S. H. 1982. Wildlife values verses human recreation: Ruby Lake National Wildlife Refuge. Trans. North Am. Wildl. Conf. 47: 553-558.

Boyle, S.A., and F.B. Samson. 1985. Effects of nonconsumptive recreation on wildlife: a review. Wildl. Soc. Bull. 13:110-116

Branche, C. M., J. M. Conn, and J. L. Annest. 1997. Personal watercraft-related injuries. J. Am. Med. Assoc. 278(3):663-665.

Bratten, S.P. 1990. Boat disturbance of Ciconiiformes in Georgia estuaries. Colonial Waterbirds 13:124-128.

Buckley, P. A., and F. G. Buckley. 1976. Guidelines for the protection and management of colonially nesting waterbirds. North Atl. Reg. Off., Natl. Park Serv., Boston, Mass.

Burger, J. 1981*a*. The effect of human activity on birds at a coastal bay. Biol. Conserv. 21:231-241.

Burger, J. 1981*b*. Effects of human disturbance on colonial species, particularly gulls. Colonial Waterbirds 4:28-35.

Burger, J. 1998. Effects of motorboats and personal watercraft on flight behavior over a colony of common terns. Condor. 100:528-534.

Burger, J., and M. Gochfeld. 1991*a*. Human activity influence and diurnal and nocturnal foraging of sanderlings *(Calidris alba).* Condor 93:259-265.

Burger, J., and M. Gochfeld. 1991*b*. Human distance and birds: tolerance and response distances of resident and migrant species in India. Environ. Conserv. 18:158-165.

Burger, J., and M. Gochfeld. 1994. Predation and effects of humans on island-nesting seabirds. Pages 39-67 in D. N. Nettleship, J. Burger, and M. Gochfeld eds., Seabirds on islands: threats, case studies and action plans. Birdlife Int., Cambridge.

Burger, J., M. Gochfeld, and L.J. Niles. 1995. Ecotourism and birds in coastal New Jersey: contrasting responses of birds, tourists, and managers. Environ. Conserv. 22:56-65.

Cairns, D. 1980. Nesting density, habitat structure and human disturbance as factors in Black Guillemot reproduction. Wilson Bull. 92:352-361.

California Environmental Protection Agency. 1998a. Draft proposal summary, proposed regulations for gasoline spark-ignition marine engines. Calif. Air Resour. Board, El Monte, Calif. 9pp.

California Environmental Protection Agency. 1998b. Staff report, public hearing to consider adaptation of emission standards and test procedures for new 2001 and later model year spark-ignition marine engines. Calif. Air Resour. Board, El Monte, Calif. 43pp.

Canandaigua Lake Pure Waters, LTD. 1999. Preliminary results of hydrocarbon testing on Canandaigua Lake, May 21-26, 1999. 14pp.

Conover, M. R., and D. E. Miller. Reaction of ring-billed gulls to predators and human disturbance at their breeding colonies. Pages 41-47 *in* proc. Colonial Waterbird Group Conf.

DeLong, A. K., and J. T. Schmidt. 1998. Draft literature review: effects of recreation on wildlife and wildlife habitat. U.S. Fish and Wildl. Serv., Stillwater Natl. Wildl. Refuge, Fallon, Nev. 48pp.

Ellis, M. R. The western and Clark’s grebe of Havasu National Wildlife Refuge analysis and management proposal. U.S. Fish and Wildl. Serv. 14pp.

Ellison, L.M., and L. Cleary. 1978. Effects of human disturbance on breeding Double-crested Cormorants. Auk 95:510-517.

Erwin, R.M. 1989. Responses to human intruders by birds nesting in colonies: experimental results and management guidelines. Colonial Waterbirds 12:104-108

Fiore, M. F., C. Hoonhout, V. Hebert, J. Herz, S. Sotomey, and G. C. Miller. 1998. Interim report on the Lake Tahoe watercraft study. Depart. of Environ. and Res. Sci., Univ. of Nev., Reno. 14pp.

Fraser, M. W. 1987. Reactions of sea-ducks to windsurfers. British Birds 80:424.

Giesy, J. P. 1997. Statement to: Tahoe Regional Planning Agency, February 26. Mich. State Univ.

Gillet, W.H., J.L. Haywood, and J.F. Stout. 1975. Effects of human activities on egg and chick mortality in a Glacous-winged Gull colony. Condor 77:492-495.

Goldman, L. 1991. Regulatory protection of coastal nongame habitats. Pages 149-152 *in* D. P. Jennings, editor. Proc. of the Coastal Nongame Workshop. U.S. Fish and Wildl. Serv. and Flor. Game and Fresh Water Fish Comm.

Green, M. L. 1990. The impacts of parasail boats on the Hawaiian humpback whale (*Megaptera novaeangliae*). Proc. Marine Mamm. Comm. Hearings.

Grubb, M. M. 1978. Effects of increased noise levels on nesting herons and egrets. Pages 49-54 *in* proc. Colonial Waterbird Group Conf.

Grubb, T.G., and R.K. King. 1991. Assessing human disturbance of breeding bald eagles with classification tree models. J. Wildl. Manage. 55:500-511.

Havasu National Wildlife Refuge. 1986. Impacts of boating activity on western grebe reproduction, final report May-October 1984-86. U.S. Fish and Wildl. Serv. 6pp.

Henson, P., and T.A. Grant. 1991. The effects of human disturbance on Trumpeter Swan breeding behavior. Wildl. Soc. Bull. 19:248-257.

Hopkins, T. E., and T. J. Doyle. 1999. Conceptual approaches to assessing potential resource impacts by watercraft in southwest Florida. Fla. Dept. of Environ. Prot. and U.S. Fish and Wildl. Serv, Naples, Fla. 7pp.

Horton, G.E. 1994. Effects of jet boats on salmonid reproduction in Alaskan streams. Masters Thesis, Univ. of Alaska Fairbanks. 118p.

Hunt, G. L. 1972. Influence of food distribution and human disturbance on the reproductive success of Herring Gulls. Ecology 53:1051-1061.

Jahn, L. R., and R. A. Hunt. 1964. Duck and coot ecology and management in Wisconsin. Mich. Dept. of Nat. Resour. Bull.73. 119pp.

Jeffery, R. G. 1987. Influence of human disturbance on the nesting success of African black oystercatchers. South Afr. J. Wildl. Res. 17(2):71-72.

Johnson, M. L. 1998. Ecological risks of MTBE in surface waters. John Muir Inst. of the Environ., Univ. of Calif., Davis. 11pp.

Jüttner, F., D. Backhaus, U. Matthias, U. Essers, R. Greiner, and B. Mahr. 1995a. Emissions of two- and four-stroke outboard engines – I. Quantification of gases and VOC. Water Res. 29(8):1976-1982.

Jüttner, F., D. Backhaus, U. Matthias, U. Essers, R. Greiner, and B. Mahr. 1995b. Emissions of two- and four-stroke outboard engines – II. Impacts on water quality. Water Res. 29(8):1976-1982.

Keller, V. E. 1991. Effects of human disturbance on eider (*Somateria mollissima*) ducklings in an estuarine habitat in Scotland. Biol. Conserv. 58:213-228.

Klein, M.L. 1993. Waterbird behavioral responses to human disturbances. Wildl. Soc. Bull. 21:31-39.

Knight, R.L., and S.K. Knight. 1984. Responses of wintering bald eagles to boating activity. J. Wildl. Mange. 48:999-1004.

Knight, R. L., and S. K. Skagen. 1986. Effects of recreational disturbance on birds of prey: a review. Pages 355-359 *in* proc. of the southwest raptor management symposium and workshop. Univ. of Ariz.

Kratzenberg, G. 1997. Declaration of Gerhard Kratzenberg concerning emissions from 2-stoke outboard marine engines. Fed. Off. of Transport, Bern, Switzerland. 31pp.

Kurby, C. R. 1975. Human interference and gull predation in cormorant colonies. Biol. Conserv. 8:23-34.

Liddle, M. J., and H. R. A. Scorgie. 1980. The effects of recreation on freshwater plants and animals: a review. Biol. Conserv. 17(1980):183-206.

Manuwal, D. A. Effect of man on marine birds: a review. Pages 141-161 in C. M. Kirkpatrick, editor. Proc. of The 1978 John S. Wright Forestry Conference, Proceedings Wildlife and People. Purdue Univ.

Mikola, J., M. Miettinen, E. Lehikoinen, and K. Lehtilia. 1994. The effects of disturbance caused by boating on survival and behavior of Velvet Scoter *Melanitta fusca* ducklings. Biol. Conserv. 67:119-124.

Miller, G. C., and M. Fiore. 1997. Final draft: preliminary study on gasoline constituents in Lake Tahoe, summer, 1997. Environ. and Res. Sci., Univ. of Nevada, Reno. 17pp.

Miller, L. K. 1998. Personal watercraft. Wichita State University, Wichita, Kans. 29pp.

Mueller, A.J., and P.O. Glass. 1988. Disturbance tolerance in a Texas waterbird colony. Colonial Waterbirds 11:119-122.

National Transportation Safety Board. 1998. Safety study - personal watercraft safety (PB98-917002, NTSB/SS-98/01). Wash., DC. 7pp.

Ollason, J.C., and G.M. Dunnet. 1980. Nest failures in the Fulmar: the effects of observers. J. of Field Ornithol. 51:39-54.

Oris, J. T., A. C. Hatch, J. E. Weinstein, R. H. Findlay, P. J. McGinn, S. A. Diamond, R. Garrett, W. Jackson, G. A. Burton, and B. Allen. 1998. Toxicity of ambient levels of motorized watercraft emissions to fish and zooplankton in Lake Tahoe, California/Nevada, USA. Eur. Soc. of Environ. Toxicol. and Chemistry.

Parsons, K.C., and J. Burgers. 1982. Human disturbance and nestling behavior in Black-crowned Night Herons. Condor 84:184-187.

Pfister, C., B.A. Harrington, and M. Lavine. 1992. The impact of human disturbance on shorebirds at a migration staging area. Biol. Conserv. 60:115-126.

Pierce, D.J., and T.R. Simons. 1986. The influence of human disturbance on Tufted Puffin breeding success. Auk 103:214-216.

Pomerantz, G. A., D. J. Decker, G. R. Goff, and K. G. Purdy. 1988. Assessing impacts of recreation on wildlife: a classification scheme. Wildl. Soc. Bull. 16:58-62.

Reuter, J. E., B. C. Allen, and C. R. Goldman. 1998. Methyl tertiary butyl ether in surface drinking water supplies. Tahoe Res. Group, Univ. of Calif., Davis. 45pp.

Revelt, J. M. 1994. The effects of marine engine exhaust emissions on water quality: summary of findings of various research studies. Memo, U.S. Environ. Prot. Agency, Engine and Vehicle Regul. Brach, Ann Arbor, Mich. 17pp.

Robert, H.C., and C.J. Ralph. 1975. Effects of human disturbance on the breeding success of gulls. Condor 77:495-499.

Roberts, G., and P. R. Evans. 1993. Responses of foraging sanderlings to human approaches. Behavior. 126(1-2):29-43.

Rodgers, J. A. Jr. 1999. Buffer zone distances to protect foraging and loafing waterbirds from disturbances by personal watercraft in Florida (Study 7520). Fla. Bur. of Wildl. Diversity Conserv., Gainesville, Fla. 15pp.

Rodgers, J. A. Jr., and H. T. Smith. 1995. Set-back distances to protect nesting bird colonies from human disturbance in Florida. Conserv. Biology 9:89-99.

Rodgers, J. A. Jr., and H. T. Smith. 1997. Buffer zone distances to protect foraging and loafing waterbirds from human disturbance in Florida. Wildl. Soc. Bull. 25(1):139-145.

Safina, C., and J. Burger. 1983. Effects of human disturbance on reproductive success in the Black Skimmer. Condor 85:164-171.

Schneider, V. M. 1987. Water sport disturbs water birds also in winter. Die Vogelwelt 108(6):201-209.

Skagen, S.K., R.L. Knight, and G.H. Orians. 1991. Human disturbances of an avian scavenging guild. Ecol. Appl. 1:215-225

Snow, S. 1989. A review of personal watercraft and their potential impact on the natural resources of Everglades National Park. Natl. Park Serv., Homestead, Fla. 80pp.

Tahoe Regional Planning Agency. 1997. Motorized watercraft environmental assessment. Tahoe Reg. Planning Agency, Calif. 145pp.

Tahoe Regional Planning Agency. 1999. Environmental Assessment for the prohibition of certain two-stroke powered watercraft. Tahoe Reg. Planning Agency, Calif. 55pp.

Tahoe Research Group. 1997. The use of 2-cycle engine watercraft on Lake Tahoe: water quality and limnological considerations. Prepared for: Meeting of Tahoe Regional Planning Agency, Governing Board Meeting. Univ. of Calif., Davis. 14pp.

Tjärnlund, U., G. Ericson, E. Lindesjöö, I. Petterson, and L. Balk. 1995. Investigations of biological effects of 2-cycle outboard engines' exhaust on fish. Mar. Environ. Res. 39(1995)313-316.

Tjärnlund, U., G. Ericson, E. Lindesjöö, I. Petterson, G. Akerman, and L. Balk. 1996. Further studies of the effects of exhaust from Two-stroke outboard motors on fish. Mar. Environ. Res. 42(1-4)267-271.

Tremblay, J., and L.N. Ellison. 1979. Effects of human disturbance on breeding Black-crowned Night Herons. Auk 96:364-369.

VanMouwerik, M., and M. Hagemann. 1999. Water Quality Concerns Related to Personal Watercraft Usage. Water Resour. Div., Natl. Park Serv., Wash. D.C.

Vos, D.K., R.A. Ryder, and W.D. Grand. 1985. Response of breeding great blue herons to human disturbance in northcentral Colorado. Colonial Waterbirds 8:13-22.

Werner, I., and D. E. Hinton. 1998. Toxicity of MTBE to freshwater organisms. School of Vet. Med., Univ. of Calif., Davis. 19pp.

York, D. 1994. Recreational-boating disturbances of natural communities and wildlife: an annotated bibliography. Natl. Biol. Serv. Biol. Rep. 22. 31pp.