Marine Matters

Knowledge of Groundwater Responses—A Critical Factor in Saving Florida's Threatened and Endangered Species Part I: Marine Ecological Disturbances

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Abstract
Florida's marine species, including threatened and endangered species, are subjected to adverse environmental conditions due to groundwater alterations because agencies charged with implementing and enforcing the Clean Water Act and Endangered Species Act fail to consider those impacts. Examples of anthropogenic groundwater perturbations that can result in direct, indirect, secondary and cumulative impacts to marine species include: (1) aquifer injection of effluent and other ecologically hazardous wastes; (2) aquifer 'storage' and 'recovery'; (3) groundwater mining; and (4) structural mining of the aquifer system (e.g., limerock, sand, phosphate). Groundwater flow in Florida's regional karst aquifer system varies greatly both spatially and temporally, in response to those anthropogenic alterations. Those perturbations can result in significant physical, chemical and biological changes in the marine ecosystem. Related adverse impacts can include: (1) predisposing organisms to disease (e.g., decreasing host resistance, increasing pathogen vigor), including catalyzation by carbon-loading; (2) introducing new pathogens; (3) promoting rapid, antagonistic evolution of microbes; and (4) introducing hazardous chemicals, including endocrine disrupters. The adverse effects of those alterations may be a significant factor in the major ecological disturbances of Florida's marine environment described in volume 18(1) of Endangered Species UPDATE. *The magnitude of adverse impacts to marine species from those groundwater perturbations is unknown. Currently, the agencies have not fulfilled their fiducal responsibilities by failing to require the necessary studies, proceeding with permitting actions in the absence of that required information, and failing to take enforcement action against existing violations.*

Background
In volume 18(1) of the *Endangered Species UPDATE*, McKay and Mulvaney (2001) provided a well-documented summary and discussion of the apparent increase in marine morbidity and mass mortality events, in addition to the emergence of new diseases spanning taxa, increases in harmful algal blooms, and longterm/ unexplained population declines in marine wildlife. They also discussed various natural and anthropogenic factors that may be contributing to the problems they described. Anthropogenic alterations of groundwater flows and groundwater contamination, however, were not included in the factors they addressed. The major causes of groundwater alterations in Florida are: (1) disposal of effluent and other hazardous liquid wastes by shallow and deep aquifer-injection; (2) aquifer 'storage' and 'recovery' (ASR); (3) groundwater mining; and (4) structural mining of the aquifer system (e.g., limerock, sand, phosphate), as summarized by Bacchus (2002). Those anthropogenic groundwater perturbations can result in significant physical, chemical, and biological changes in the marine ecosystem; concomitant adverse impacts on marine organisms (including threatened and endangered species); and a "taking" of critical habitat. This article is the first in a series addressing implications of anthropogenic groundwater alterations

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in Florida, and addresses the role of those alterations as potential causal factors in the myriad unexplained disease outbreaks and deaths of marine organisms in Florida since 1980 (see Table 1 in McKay and Mulvaney 2001).

Federal and Florida laws require consideration of all adverse impacts (direct, indirect, secondary and cumulative) of projects that are proposed to be permitted and to take enforcement action against violations. The Scientific Advisory Board (SAB) of the United States Environmental Protection Agency (EPA) recently determined that hydrologic alterations represent a major environmental stressor (SAB 1999). The intimate interconnection between Florida's various aquifer layers and surface water (via fractures, dissolution/collapse features, paleochannels, and other discontinuities) has been established in the scientific literature (summarized by Bacchus 2000a; 2000b; 2002) and case law, and will be addressed in a subsequent article in this series. This intimate interconnection in Florida's karst aquifer system results in both spatial and temporal responses to anthropogenic alterations. Despite these facts, the large-scale, long-term adverse impacts due to groundwater alterations currently are not considered by agencies charged with implementing and enforcing the Clean Water Act and the Endangered Species Act in Florida.

The "First Biennial Report to Congress, 1996" by the EPA is one example of the failure to recognize impacts of groundwater perturbations (EPA 1996). That report addressed restoring historical freshwater flow to Florida Bay and conducting research to understand the effect of water transport from Florida Bay on water quality and resources in the Florida Keys National Marine Sanctuary ('Sanctuary'). No studies have been initiated or proposed to evaluate the effect that diversion of historic, fresh groundwater discharge from these sensitive areas has had on the ecosystems of the 'Sanctuary.' Likewise, the impacts of deep and shallow injected effluent on the sensitive resources of the 'Sanctuary' and newly-created Tortugas Marine Reserve ('Reserve') have not been determined. The only reference to deep-well injection in the EPA's report was that it be "evaluated and implemented" by the City of Key West. Although deep-well injection of effluent in Key West was scheduled to begin in spring 2001 (City of Key West 2000), no Environmental Impact Statement (EIS) or other comprehensive scientific investigation has been conducted to evaluate the potential impacts of that proposed action. Migration of injected effluent has been documented or is suspected to be occurring in 42 of the 81 operational deep-injection sites (National Archives and Records Administration 2000), which are located primarily along south Florida's coast (Figure 1). Therefore, the pending permit by the Florida Department of Environmental Protection (FDEP) authorizing deep-well injection of secondarily-treated sewage effluent in Key West has major implications for both the 'Sanctuary' and newly-created 'Reserve.'

If activated, the Key West deep-well injection facility would be considerably closer to the newly-created 'Reserve' than the Miami/Dade Blackpoint sewage treatment plant, which is located adjacent to Biscayne Bay at the northern extent of the 'Sanctuary.' Recent data from Top et al. (2001) support the conclusion that extensive preferential induced discharge of deep-aquifer water is occurring within the 'Sanctuary' (including in proximity to coral reefs), as a result of effluent-injection at the Miami/Dade facility. Additional support for the induced discharge of deep and shallow injected effluent is provided by the: (1) 1994 documented pulses of fresh water lowering ambient salinity from approximately 35 ppt to 28 ppt in ground water discharging from the base of a deep reef near Carysfort Reef, in Biscayne National Park (R. Curry, unpublished data); (2) previous discovery of low-salinity water seeping from the base of deep coral reefs off Key Largo (Simmons, Jr. 1992); (3) 1983 groundwater discharges from the bases of Carysfort and French Reefs, with salinities as low as 10 ppt (where ambient salinity was 33 ppt), and numerous pesticide peaks and heavy metal (cadmium, chromium, copper, iron, lead, mercury, and zinc) concentrations ranging from 100 to 10,000 times greater than mean sea water values (Simmons Jr. and Love 1987); and (4) initial observation of "white plague" coral disease (now in epidemic proportions) at Carysfort Reef soon after aquifer-injection of effluent was initiated at the Miami/Dade facility (Dustan 1999). Aquifer-injection of 110 million gallons each day of secondarily-treated effluent has been permitted at the Miami/Dade facility since before the time of the marine incidences described in Table 1 of McKay and Mulvaney (2001). Such apparent wide-spread induced discharges of ground water further suggest that the proposed ASR injection of 1.7 billion gallons of surface water in the Everglades Restoration Plan (U. S. Army Corps of Engineers and South Florida Water Management District 1999, and as proposed using contaminated surface water by the Florida Legislature in 2001) ultimately would result in more extensive induced discharge of injected contaminants throughout Florida Bay, the coral reef tracts in the 'Sanctuary,' and the Everglades.

The FDEP currently is proposing to double the volume of minimally-treated effluent at the Miami/Dade facility, despite documented viola-

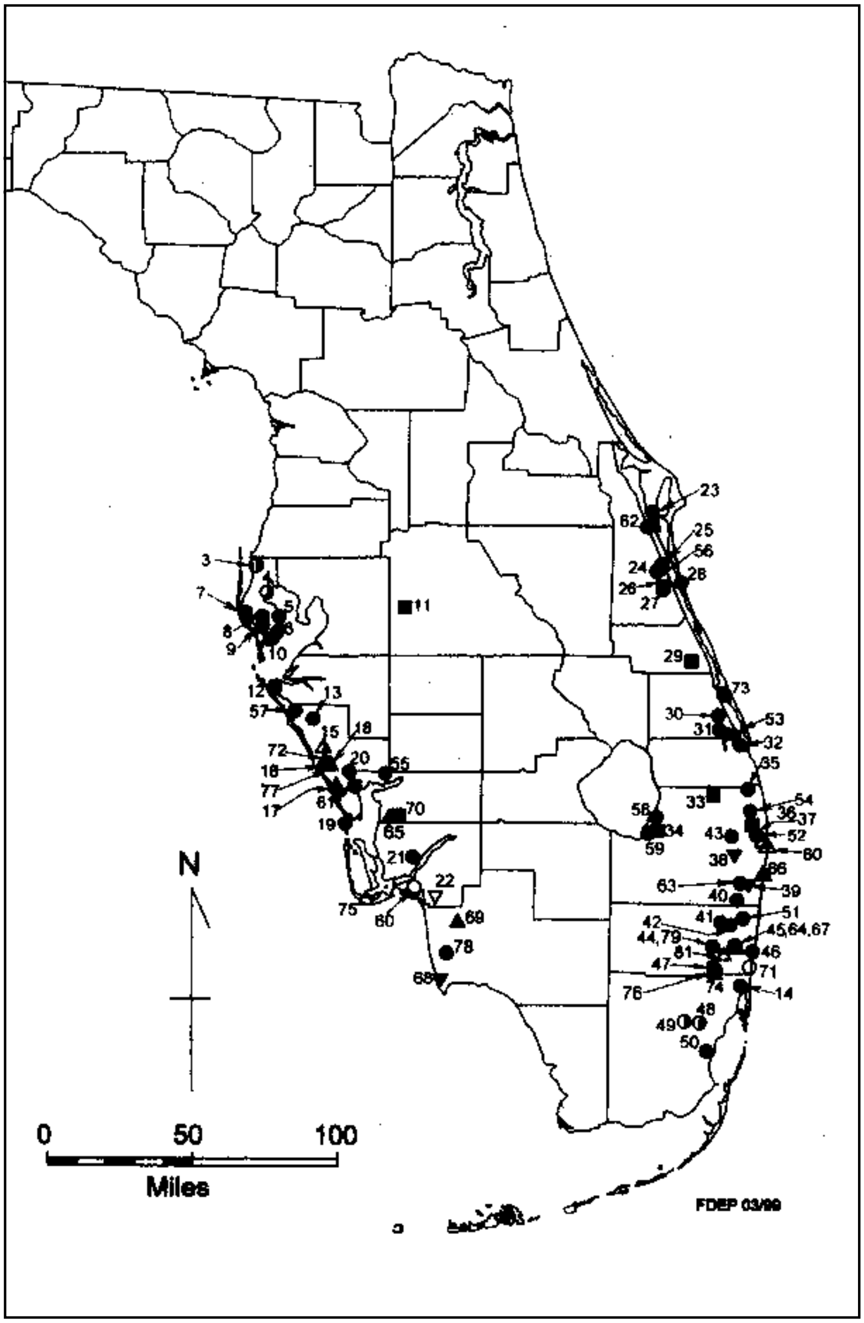

Figure 1. Location of Class I deep-well injection facilities in south Florida, with the Miami/Dade Blackpoint effluent-injection facility (50) shown as the southeasternmost facility, as of 2000 (from Florida Department of Environmental Protection 1999).

tions of the existing permit, including migration of injected effluent (addressed in part by McNeill 2000). The engineering firm responsible for the Miami/Dade aquifer-injection wells also constructed the injection wells proposed for aquifer-injection of minimally-treated municipal effluent in Key West. Rapid induced discharges into the 'Sanctuary' have been documented via shallow injection wells in the Florida Keys (e.g., Corbett et al. 2000; Dillon et al. 2000; Paul et al. 1997). Injection of effluent and other ecologically hazardous wastes into Florida's karst aquifer system, via shallow and deep wells, is conducted under FDEP's Underground Injection Control rule. The title of that rule is grossly misleading because injected contaminants are uncontrollable. Minimally-treated effluent is injected into the shallow aquifer via approximately 1,000 wells throughout the Keys. An FDEP permit is pending for shallow-aquifer injections adjacent to the last remaining sea turtle nesting beach in the Upper Keys (Division of Administrative Hearings 2000). Marine species designated to receive federal protection in south Florida's Keys/Monroe County include the American crocodile (*Crocodylus acutus*) and manatee (*Trichechus manatus*), in addition to the following four species of sea turtles: loggerhead (*Caretta caretta*), green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), and Kemp's ridley (*Lepidochelys kempi*). Numerous other federally-listed species and species recognized by the State of Florida as threatened, endangered or species of special concern also occur within the Florida Keys/Monroe County. The agency actions and inactions referenced above particularly are negligent in light of the fiducial responsibility of the government, our current level of knowledge, and the public admission of violations to the aquifer-injection rules. Environmentally-sound alternatives are available, but are not being implemented.

Although there is extensive evidence that all four major causes of groundwater alterations referenced initially are contributing to the marine disturbances in Florida (see Bacchus 2002), as summarized by McKay and Mulvaney (2001), only the potential 'difusion' of nutrients (nitrogen and phosphorus) from shallow injection wells is being considered (see Lapointe 2000). Agencies authorizing the construction and operation of ASR injection wells and other groundwater alterations have not: (1) identified the preferential flow paths that are known to exist; (2) monitored the frequency, volume, and chemical characteristics of the discharges via these preferential flow paths; or (3) determined the ecological impacts of such discharges. Because of this narrow focus, major federal initiatives such as the "Harmful Algal Blooms and Hypoxia Research and Control Act of 1998" (P. L. 105-383), contributing more than $52 million to address the problem of harmful algal blooms and hypoxia in the Gulf of Mexico, may fail to identify induced discharge of contaminated ground water as a significant fact in coastal eutrophication. Top et al. (2001) described kills of finfish and shellfish that were linked to groundwater-laden nutrients, providing examples of Atlantic coastal areas where ground water accounted for half of the nitrogen loading of the sediments. This article departs from the narrow focus on nitrogen and phosphorus as the sole potential impacts from aquifer injection (effluent, other ecologically hazardous fluids, ASR). Some of the numerous other related adverse impacts, including to federally-listed species, can include: (1) predisposing marine organisms to disease (e.g., decreasing host resistance, increasing pathogen vigor), including catalyzation by carbon-loading; (2) introducing new pathogens to the nearshore marine environment; (3) promoting rapid, antagonistic 'evolution' of microbes; and (4) introducing hazardous chemicals, including endocrine disrupters, to the nearshore marine ecosystem.

Predisposition to disease, and beyond

Groundwater mining and structural mining of the aquifer system result in hydrologic perturbations such as the interception/diversion of pristine, low-salinity, low-nutrient submarine groundwater discharge (SGD) of constant temperature. Aquifer injection of fluids can replace this pristine resource with treated effluent. Those perturbations can induce a state of physiological distress in Florida's marine ecosystems. Physiological distress, in turn, can promote predisposition to disease caused by pathogens present historically, or introduced recently (e.g., via injected effluent or transported African dust). It also could render organisms more susceptible to other stressors (see Bacchus 2002). For example, coral reefs have experienced significant adverse impacts both directly (Bell 1992) and indirectly, via algal proliferation (Lapointe 1999), with the addition of extremely low levels of nitrogen (0.014 mg L^{-1}) and phosphorus (0.06 mg L^{-1}). Levels of those nutrients in effluent that has received advanced wastewater treatment (AWT) and subsequent 'polishing' are approximately two orders of magnitude greater than the levels of nutrients that can cause those adverse impacts (FDEP, unpublished data). Despite the adverse marine impacts that can occur from nutrient loading, no consideration is being given to other components of the injected, secondarily-treated effluent (and other contaminated fluids) that may pose a comparable or greater threat than the nutrients. The following section describes the potential role of introduced carbon, in conjunction with groundwater perturbations, in predisposing marine organisms to diseases and death.

Carbon as an anthropogenic, catalystic environmental stressor

Aspergillus sydowii is a fungus implicated in mass mortalities of sea fans (*Gorgonia*), as discussed by McKay and Mulvaney (2001). This fungus is a common, cosmopolitan, saprobic fungus, however, isolated from many types of terrestrial environments, including soils from Alaska to the tropics. It also has been cultured from subtropical marine waters near the Bahamas and the Straits of Florida, and has been found in eulittoral zones and oceanic zones, including isolations from waters collected as deep as 4,450 m (13,350 ft). This fungal species had not been recognized as the cause of widespread disease in plants or animals prior to the mass mortalities of sea fans. Several species of *Aspergillus* are opportunistic animal pathogens, generally infecting individuals with compromised immune systems. Likewise, the infection of sea fans by *A. sydowii* may be the result of opportunistic pathogenicity due to weakening of the host from stressors, such as water pollution or other environmental factors (Geiser et al. 1998; Nagelkerken et al. 1997; Roth et al. 1964; Smith et al. 1996). Rinaldi (1983) described the role of the compromised host in the invasive fungal disease of humans by species of the genus *Aspergillus*. The significance of host vigor in avoiding infection by this fungus was emphasized.

Other factors that may influence the ability of a pathogen to infect its host include competition between the pathogen and competing antagonists. *Trichoderma*, another fungus commonly found in soils, is regarded as an antagonist of fungal pathogens. *Trichoderma* exhibited reduced competitive ability in laboratory experiments when higher concentrations of carbon (C) were present, relative to available nitrogen (N). That finding suggests a delicately balanced C/N ratio is required for maximum competition (Overmier 1975). During the same experiments, the fungal pathogen *Gliocladium virens* required high levels of C for successful invasion of *Diplodia* colonies. Therefore, the C/N ratio may influence pathogenicity by affecting the competitive ability of antagonists, or by increasing the ability of fungal pathogens to invade their host, independent of any increased susceptibility of the host organism due to other stressors.

Despite the fact that disruption of the C/N ratio can facilitate infection by opportunistic fungi, not all organisms exhibit equal susceptibility to infection. Organisms that are more sensitive to environmental perturbations are considered the 'canaries' that issue early warnings. These hypersensitive indicator organisms (e.g., sea fans, certain species of corals) respond more rapidly and severely to perturbations, often succumbing to infection by fungi, bacteria or viruses.

Mass mortality of seagrasses in Florida Bay is similar to the mass mortality of sea fans. The seagrasses also became victims of a fungus considered to be a nonaggressive (opportunistic) species on seagrasses throughout south Florida (J. Zieman, personal communication). This fungus is a marine slime mold (*Labyrinthula* sp.) identified as endemic to the south Florida area. Therefore, it does not occur in Africa, the origin of the aerially-dispersed dust in the African dust theory (as discussed by McKay and Mulvaney 2001, and challenged by Bacchus 2002). Furthermore, that marine slime mold does not produce the type of resistant structures that would allow long-range aerial distribution (D. Porter, personal communication). Therefore, it is unlikely that the African dust dispersed across the ocean is the source of the pathogen implicated in the mass mortality of the seagrasses in Florida Bay.

Seagrasses, like other organisms, can be weakened by environmental stressors and made more vulnerable to disease (Den Hartog 1987; Muehlstein 1989; Short et al. 1988). The mass die-off of seagrasses in Florida Bay in 1987, reportedly was due to hypersaline conditions in Florida Bay during a period of low rainfall. Our current state of knowledge, however, suggests that the hypersaline event was not due to low rainfall alone (e.g., impacts of groundwater mining) and was not the sole or possibly even the most significant stressor (summarized by Bacchus 2002). The similar die-off of seagrasses in Cockburn Sound, Western Australia (also summarized by Bacchus 2002) suggests that induced discharge of injected waste water played a significant role in predisposing seagrasses in Florida Bay to the opportunistic fungal disease.

Durako and Kuss (1994) suggested that the die-off of turtle-grass (*Thalassia testudinum*) in Florida Bay was density-dependent because it was observed only in areas that previously supported very dense populations of turtle-grass. They also noted that the lower density stands that were less affected by the die-off also were in areas of lower salinity. Possibly, the denser stands of turtle-grass were associated with areas of historic SGD that originally provided more favorable growing conditions for the turtle-grass. In addition, those areas of SGD subsequently could have become areas where saline water from deeper aquifers was surfacing (supported by data from Top et al. 2001) as induced recharge, due to deep-well injected effluent. Point discharges of excessive nutrients and other contaminants could have reduced the vigor of seagrasses and increased the vigor of pathogens (e.g., the undescribed marine slime mold).

Duarte (1995) provided extensive insight into the feedback mechanisms leading to the "domino effect," as coastal eutrophication results in a shift from ecosystems dominated by relatively slow-growing, nutrient-conserving macrophytes such as seagrasses, to systems dominated by rapidly growing phytoplankton and macroalgae. In the latter case, greater amounts of dissolved organic C are released and available for recycling. *Ceramium corniculatum*, the red alga that was reported covering the coral reefs at Cheeca Rocks, is an example of the thin, finely-textured macroalgae described by Duarte that results in the "domino effect", the rapid release and recycling of C. Cheeca Rocks is a shallow coral reef system in close proximity to numerous shallow effluent-injection wells in the Upper Keys.

The sensitivity of corals to increases in C was demonstrated by Mitchell and Chet (1975) with coral heads exposed to low concentrations of various substances, including crude oil (100 ppm) and organic matter (1000 ppm, in the form of dextrose), under controlled laboratory conditions. Many of the coral colonies died after exposure to low concentrations of crude oil for 24 hours. Addition of organic matter (dextrose) resulted in the same level of increased mucus production associated with exposure of coral heads to crude oil. In fact, corals died within 24 hours after dextrose was added to the water. Concomitantly, the bacterial population associated with the coral heads "reached an extraordinarily high peak" of 10^7 cells ml^{-1} within 24 hours after addition of dextrose.

Bacterial isolates from the coral surface in the presence of crude oil indicated that 15 to 25% of bacteria isolated were capable of growing on coral tissue extract as the sole C and N source. That finding suggested those bacteria could co-occur with corals in low numbers under natural, oligotrophic conditions, without external sources of nutrients. Of equal significance, they discovered that approximately 60% of the bacteria identified in those experiments were motile, gram negative rods. They further noted that more than 50% of the motile bacteria displayed chemotaxis (chemical attraction) to the coral mucus. The majority of those bacteria also were capable of growing on coral tissue extract as the sole C and N source.

Corals produce mucus in response to both chemical (e.g., C compounds) and physical (e.g., sand) stressors. Coral mucus is composed of polysaccharides, molecules containing many sugars (which are composed of C atoms). Although dextrose is not considered a toxic substance, it is a source of C, as is the mucus that is produced by the corals when they are under stress. Microbes, such as bacteria and fungi, use C as a food source. In the experiment conducted by Mitchell and Chet (1975), the bacterial population associated with the coral heads increased at the same rate as the production of mucus by the coral. Their experiments with antibiotics (penicillin and streptomycin) illustrated that coral death was due to the bacteria (including two predatory bacteria), rather than the actual stressors. Results were the same, even with an order of magnitude increase in crude oil concentration. Their research was critical in showing that even when concentrations of pollutants were insufficient to kill the corals directly, the increased stimulation of omnipresent microbes and microbial processes was sufficient to cause coral death.

The role of increased C in coral deaths documented by Mitchell and Chet (1975) supports concerns by Dustan regarding the implication of C-loading and coral death (Dustan 1999, personal communication), and by Bacchus (2002) regarding disruption of the C/N ratio. Therefore, injection wells at the Miami/Dade facility and throughout the Keys are implicated in the demise of the coral reefs via C-loading and disruption of the C/N ratio. Likewise, additional C entering the water near the coral reefs, via induced discharge of injected effluent, may be a factor in the assault of corals by *Sphingomonas* (white plague). Initially, white plague was reported from coral reefs near the northern boundary of the 'Sanctuary' at approximately the time that the Miami/Dade facility began injecting effluent adjacent to Biscayne Bay. *Sphingomonas* is representative of the ultramicrobacteria in oligotrophic marine waters (Fegatella and Cavicchioli 2000).

Edwards (2000) reiterates the differences in responses of microorganisms under artificially nutrient-rich conditions and their natural, oligotrophic environments where they are exposed to starvation conditions and grow slowly, or not at all. The presence of organic matter in the water column also has been shown to increase the survival time of bacterial pathogens in the water, such as *Vibrio cholerae*, the human pathogen that causes cholera (Joseph and Bhat 2000). More chilling is the mounting evidence that symbiotic organisms (e.g., bacteria, fungi) can become pathogenic towards their hosts under abnormal conditions (Bacchus, unpublished data; Hentschel et al. 2000).

Another unaddressed aspect of C-loading, via induced discharge of injected effluent, is the potential interaction of this organic material with chemicals added to the effluent during the treatment process. Effluent injected throughout the Keys typically is treated with chlorine, generally without dechlorination. When chlorine comes into contact with organic matter it can form compounds known as trihalomethanes (chloroform, bromoform, dibromochloromethane, and bromodichloromethane). Those compounds have been classified as probable human carcinogens. In addition to the organic matter in the minimally-treated effluent injected at the Miami/Dade facility and throughout the Keys, approximately half of the SGD areas of direct discharge observed during a recent reconnaissance in the Florida Keys had thick layers of organic material associated with them (Bacchus, unpublished data). Previous studies also have documented organic layers within living coral reefs associated with the Florida Keys (summarized in Bacchus 2001). If direct discharge of injected effluent (which also contains organic material and is heavily-chlorinated) is occurring via preferential flow paths, such as those with associated organic layers in the Keys, organisms exposed to this water could experience significant adverse impacts.

No research appears to have been done to determine if exposure of marine animals to wastes discharging in nearshore waters could contribute to conditions such as the recent proliferation of tumors in sea turtles (Figure 2), or other recent increases in unexplained diseases and deaths of marine organisms. A recent study in the Keys by Swart et al. (2000), however, provided additional evidence of nearshore discharge of injected effluent. Of the 50 locations sampled in the study, Anne's Beach exhibited one of the highest concentrations of coprostanol and cholesterol (indicators of human sewage). Anne's Beach is an extensive undeveloped stretch of naturally-vegetated beach lacking septic systems, cess pits, and related sources of sewage that were the focus of that study. The source of those human sewage indicators was not known (P. Swart, personal communication). The sewage, however, may represent a threat to sea turtles at the last remaining sea turtle nesting beach in the Upper Keys, north of Anne's Beach, as well as to humans. Shallow injection wells operate in close proximity to Anne's Beach.

Implications described above, coupled with increasing incidence of unexplained/unidentifiable diseases and mortality in other marine organisms (including federally-listed species) provide sufficient impetus for a total moratorium on the increase in number of injection wells and volume of injected fluids in the Keys vicinity until a comprehensive investigation of the potential impact of injected wastes on coastal ecosystems and associated organisms is completed. Additional potential adverse impacts are described below.

Newly-introduced pathogens and rapid, antagonistic evolution

The preceding discussion addressed the ability of environmental conditions subjected to anthropogenic alterations to increase susceptibility of (predispose) organisms like corals and seagrasses to infection by commonly-occurring, opportunistic pathogens. Also addressed was the potential for altered environmental conditions to increase the virulence of commonly-occurring pathogens. A related scenario is the introduction of pathogens (viruses, fungi and bacteria) into environments foreign to those in which they evolved.

The first relevant example is the injection of large volumes of effluent containing human pathogens into a karst aquifer system, with subsequent induced discharge into the marine environment. The second example is the State of Florida's repeated attempts to initiate large-scale injection of surface water, via ASR, as referenced previously. The ASR injections (1.7 billion gallons per day planned in the vicinity of Lake Okeechobee) are promoted as the critical component in 'restoration' of the Everglades (U. S. Army Corps of Engineers and South Florida Water Management District 1999). This approach, however, appears to be more closely linked to the presumption that ASR would increase the amount of water available to support more extensive development in the Everglades watershed. There is, however, no scientific support for that presumption. Although Governor Bush's (R-FL) attempts were unsuccessful this year to pass legislation allowing large-scale injection of untreated surface water throughout Florida, efforts are underway to begin aquifer-injections of untreated surface waters in south Florida as experiments.

There are at least two significant differences between the dispersal/discharge of microbes in effluent via groundwater flow channels and disposal via ocean outfall pipes. The first is the cooler, more stable temperature of groundwater transport of effluent. The second is the potential for longer periods of incubation in the absence of light. Both conditions can

Figure 2. Necropsy of a green sea turtle (*Chelonia mydas*) from Florida's Upper Keys, where minimally-treated effluent injected into deep and shallow aquifers appears to be discharging into nearshore surface waters. The large white mass is a tumor engulfing both kidneys (photograph courtesy of Sue Schaf, The Turtle Hospital 1999).

extend the period of viability for at least some pathogens (J. Paul, personal communication). Finally, consideration must be given to the possibility that introduction of microbes into a new environment, or exposure of existing organisms to altered environmental conditions, may facilitate evolution of new organisms, as is suggested by recent findings (see Bacchus 2002). This is of equal concern with respect to the contaminated surface water (agricultural and urban runoff) that Florida proposes to inject as ASR. Concerns are mounting that even if organisms in injected surface water did "die-off," as proponents suggest, that toxins, such as those produced by dense concentrations of bluegreen algae, would be unaffected during the 'storage' period, as would other chemical contaminants.

Mounting evidence also suggests that organisms with rapid regeneration times (e.g., microbes) are evolving equally rapidly in the severely disturbed environments we are creating. This is true particularly for sewage-laden, eutrophic coastal waters. For example, Parveen et al. (1997) used multiple-antibiotic-resistance profile homology to determine that *E. coli* isolates from point source sewage discharge were markedly more diverse than isolates from nonpoint sources, such as stormwater runoff. Those findings provide additional evidence that both our natural resistance, and our medical resistance to these organisms are under serious threat.

Responses are similar at the ecosystem level. Burkholder and Glasgow, Jr. (1997), Burkholder et al. (1995), and Glasgow, Jr. et al. (1995) provide disturbing details regarding increasing frequency, magnitude, severity, and range of outbreaks of toxic ambush-predator dinoflagellates in coastal areas of the southern United States. Those organisms were undescribed and unknown to science until recently. The marine slime mold implicated in the mass mortality of seagrasses in Florida Bay may represent another example of microbes evolving rapidly in coastal areas where significant anthropogenic eutrophication and other pollutants are increasing.

As an example of the situation in the 'Sanctuary' administered by the National Oceanic and Atmospheric Administration (NOAA), research conducted at coral reefs throughout the 'Sanctuary' not only documented increases in coral diseases and deaths described previously, but also revealed that no recruitment of reef-building coral species was occurring (Tougas and Porter 2002). Ironically, recruitment of reef-building coral species is occurring at other locations in the Caribbean. The prospects of the reef corals, the interdependent reef species, and other coastal organisms, including federally-listed species, surviving those recent, anthropogenic assaults in Florida do not look optimistic.

Parts per million vs. parts per billion and trillion

In addition to increasing the spatial scale of perceived contributors to the environmental problems in south Florida (e.g., regional groundwater perturbations), we also must decrease the scale of our focus with respect to potential water quality contaminants (e.g., increased sensitivity of detection). For example, no monitoring currently is being conducted to evaluate the introduction/escalation of endocrine disruptors in south Florida's coastal waters. Environmental monitoring focuses on the toxic impacts of pollutants (often in the range of parts per million), rather than impacts of pollutants that disrupt the normal functioning of hormones (usually in the range of parts per billion or parts per trillion). The former can lead to death of the organism exposed to the contaminant, while the latter can result in loss of future generations of exposed organisms.

Colborn compared (1) nonlethal (low) levels of compounds that cause toxic responses to organisms and (2) orders of magnitude lower levels of endocrine disruptive compounds that may be 'lethal' to all future generations, after exposure of the initial generation (see Figure 7 of Bacchus 2002). In some cases, hazardous levels of endocrine disruptors may be below current detection limits of sampling equipment (T. Colborn, personal communication). Harmful compounds also can bioaccumulate. For example, algae can take up and concentrate pollutants (other than nutrients) from minimally-treated sewage, like the effluent injected throughout the Keys. The die-off of the sea urchin (*Diadema antillarum*) population in the Keys may have been due to contaminants in the algae (primary food source of sea urchins) that it consumed, or to compounds (e.g., nonylphenol/ethoxylates) in discharged ground water associated with the reefs. Recall that adverse impacts of those compounds include disruption of the reproductive process, generally being revealed in subsequent populations. The importance of this possibility is more significant since The Nature Conservancy is devoting the financial and personal resources of its organization to "rearing laboratory urchins for eventual release onto the coral reefs," according to the Florida Chapter's Spring 2001 newsletter.

Synthetic chemicals (e.g., nonylphenol and its breakdown products) are capable of disrupting hormonal function, and are becoming more widespread in the environment. Those compounds are biotransformed to several stable metabolic products, including nonylphenol and its breakdown products. Many of those compounds, including nonylphenol, are lipophilic. Therefore, they are stored in fatty tissue, and are considerably more toxic than the parent compound (Giger et al. 1984; 1987; Granmo et al. 1989; Holt et al. 1992; Li and Schroder 2000; Reinhard et al. 1982).

Those compounds can function as estrogen mimics. Estrogen mimics can cause deformities in penises and testicles, in addition to reducing sperm counts in males exposed to those chemicals. Exposure to very small concentrations of these estrogen mimic compounds also has caused breast cancer cells to proliferate under laboratory conditions (Colborn et al. 1996). Marine mammals bioaccumulate nonylphenol (Ekelund et al. 1990). In addition to being components of household and industrial detergents, those compounds are added to products such as polystyrene and polyvinyl chloride (PVC) as an antioxidant to make the plastics more stable and less brittle, and to pesticides, contraceptive creams, and personal care products. Those chemicals can leach into water. Bacteria in animals' bodies, in the environment, and in sewage treatment plants (STPs) degrade those compounds into nonylphenol and other chemicals that can mimic estrogens (Colborn et al. 1996).

Approximately 40% (molar concentration) of the total nonylphenol in STPs can reach surface waters via secondary effluents (Ahel et al. 1994). During the 1980s, fish in streams exposed to discharge from STPs in England appeared to be sexually confused, containing characteristics of both sexes. Controlled tests were conducted with caged fish exposed to water flowing from the STP. After 3 weeks of exposure, levels of the estrogen "marker" in the fish exposed to the STP water in the stream had increased 1,000 times more than levels in control fish. In the summer of 1988, a nationwide study was conducted at 28 sites in England and Wales. Dramatic increases in the estrogen "marker" were found in all cases where the fish remained alive through the tests. In one case the increase in the marker for the exposed fish was 100,000 times the level in the control (Colborn et al. 1996; Jobling et al. 1998).

The use of alkylphenols, the breakdown product of alkylphenol polyethoxylates contained in detergents, was a strong suspect. Extended research tested fish exposed to alkylphenols to determine if: (1) these compounds caused estrogenic responses in fish similar to responses in breast cancer cells in the laboratory and (2) levels in the environment were high enough to cause the estrogenic responses in the fish. The answer to both questions was yes. The authors noted, however, that a range of chemicals could be contributing to the response observed in the fish exposed to streams with STP discharge (Colborn et al. 1996; Jobling et al. 1998). Toxicity of nonylphenol and its breakdown products to other organisms, including coastal organisms, also have been documented (Granmo et al. 1989).

The use of alkylphenol polyethoxylates has increased since the 1940s. Because of concern expressed during the past decade regarding the persistence and toxicity of these chemicals to aquatic life, several European countries banned use of the most common of these chemicals in household cleaners by the late 1980s. Additionally, 14 European and Scandinavian countries were to phase out use by 2000 (Colborn et al. 1996). In 1995, nonylphenol and its ethoxylates (NPEs) were added to Canada's list of substances that are toxic or are capable of becoming toxic. Partial justification for this concern was the presence of nonylphenol and NPEs in the effluent from municipal STPs and the knowledge that nonylphenol and NPEs have been shown to produce endocrine disrupting effects in fish and other organisms. An environmental risk assessment conducted recently in Canada determined that nonylphenol also should be considered toxic, based on the Canadian Environmental Protection Act (Davidson et al. 2000).

Currently, neither the EPA, nor FDEP have required or initiated monitoring to determine if estrogen mimic compounds (or any other harmful chemicals) are present in the treated effluent that is being injected into the highly permeable aquifers in south Florida. In fact, not only does the EPA not regulate, or require monitoring for nonylphenol and related compounds in drinking water in the United States, nonylphenol has not been placed on that agency's waiting list of compounds of concern, to be investigated in the immediate future (EPA Hot Line/Labat-Anderson, personal communication). Consequently, even effluent reportedly treated to "drinking water standards" can contain hazardous and toxic levels of nonylphenol and its breakdown products. Therefore, claims by the EPA that treatment of injected effluent will be upgraded to "drinking water standards" is of little value, even from a water quality standpoint.

Summary

Effluent injected into shallow wells in the Florida Keys has been shown to discharge rapidly into surface waters, including near sensitive coral reef ecosystems in the NOAA 'Sanctuary.' Studies similar to those conducted for shallow injection wells have not been conducted for deep injection wells, like those injecting minimally-treated effluent at the Miami/Dade facility and similar injections pending in Key West. Most recent results, however, suggest that induced discharge related to deep-well injection from that facility is occurring throughout the NOAA 'Sanctuary.' No information is available regarding the degree to which the treated effluent (even at "drinking water standards") injected into deep wells may be transporting ecologically hazardous and toxic substances, such as endocrine disruptors, to sensitive coastal ecosystems (e.g., the NOAA 'Sanctuary').

Nutrients have been the sole focus of the effluent-related studies in the Keys, in part because the rapidly increasing eutrophication is obvious even to the casual observer, due to planktonic and macro-algal blooms. Even if there was reliable scientific evidence to support the belief that significant amounts of excess nutrients in injected effluent were being adsorbed/taken up by the carbonate aquifers (and there is not), that information would not suggest that other pollutants (e.g., excess C, endocrine disruptors, viruses) were being adsorbed/diluted similarly, prior to discharging into environmentally sensitive areas like the 'Sanctuary.'

Likewise, even if contaminants such as endocrine disruptors were subjected to the same theoretical dilution processes as N and P, the environmental damage from endocrine disruptors occurs at concentrations orders of magnitudes lower than for nutrient pollutants. Therefore, even at highly diluted concentrations those compounds could present a significant environmental hazard to organisms in Florida Bay, as well as associated coral reefs in the NOAA 'Sanctuary' and newly-created 'Reserve.' The current state of knowledge regarding adverse impacts associated with aquifer-injection in south Florida provides support for a moratorium on any increase in the number of injection wells and the volume of injected fluids in south Florida until extensive investigations are conducted to determine the full extent of the damage that has occurred.

Conclusions

The regional karst aquifer system underlying south Florida is not a static system, but changes spatially and temporally, particularly in response to anthropogenic perturbations. The historic submarine groundwater discharge in south Florida occurred from the margin of the submerged carbonate platform, outcrops in terraces, and areas of discontinuities (e.g., karst dissolution/subsidence features, paleo channels). Data suggest that the historic discharge of pristine, low-salinity, low-nutrient ground water of constant temperature into Florida's coastal areas was significant in maintaining the associated ecosystems. The quantity and quality of that historic SGD has been and will be altered by: (1) aquifer injection of effluent and other ecologically hazardous wastes, (2) aquifer 'storage' and 'recovery,' (3) groundwater mining, and (4) structural mining of the aquifer system (e.g., limerock, sand, phosphate).

The same subsurface flow paths that supplied historic pristine ground water to coastal areas now may be points of preferential induced discharge for fluid wastes injected into wells along south Florida's coast. The 110 million gallons a day of minimally-treated sewage permitted for injection at the Miami/Dade facility, and smaller volumes injected in approximately 1,000 shallow wells throughout the Florida Keys, in addition to the 1.7 billion gallons of surface water proposed for ASR injection in south Florida are examples. Minimal dilution, dispersion, and adsorption should be expected for injected contaminants due, in part, to rapid travel times in the aquifer, prior to induced discharge into nearshore surface waters.

Current literature suggests that induced discharges containing aquifer-injected contaminants are occurring in the Gulf of Mexico, Straits of Florida, Gulf Stream, and Atlantic Ocean, and may be a factor in harmful algal blooms and hypoxia. Government agencies charged with implementing and enforcing the Clean Water Act and the Endangered Species Act have failed to consider the direct, indirect, secondary, and cumulative impacts of those groundwater alterations to Florida's marine species, including threatened and endangered species. By proceeding with permitting actions, in the absence of the required information, the agencies are negligent and therefore liable.

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Book Review

Oceanographic Processes of Coral Reefs: Physical and Biological Links in the Great Barrier Reef
by Eric Wolanski

Oceanographic processes are crucial to the understanding of coral reefs yet are often downplayed in attempts to explain how these intricate ecosystems function. Volumes that integrate the biological, physical, and chemical aspects of this subject are also rare. Eric Wolanski, however, has produced a very useful book and CDROM that will give readers an introduction to the biological and physical oceanographic processes of coral reefs. He has done this by focusing the book's subject matter on the key processes that underpin the world's largest continuous reef system, the Great Barrier Reef. Despite its Australian focus, this book will be highly useful for coral reef researchers everywhere. Chapters in the excellent text span the broad-scale regional processes, local oceanography, biological communities, and anthropogenic influences on coral reefs. An overriding theme of the book is the important role that linkages play within this ecosystem, whether these are between land and reef, or between individual reef components. The book also provides an excellent text for university courses that want an up-to-date and modern synthesis of the important oceanographic processes that define coral reefs.

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