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Turning Off the Heat: Impacts of Power Plant Decommissioning on Green Turtle Research in San Diego Bay

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*Green turtles (*Chelonia mydas*) are among the most high profile species in San Diego Bay, California, and understanding impacts of coastal development and industry is essential to the management and conservation of this local population. Here we describe power plant changing energy production and its impact on turtle habitat use and our ability to research and manage this population. For over 20 years, green sea turtles have been captured, assessed, and tagged near the South Bay Power Plant (SBPP) in the San Diego Bay; from 2002–2011, 104 turtles were captured on 212 occasions. As the 50-year-old SBPP generates less energy, effluent patterns change and water temperatures decrease, presumably to more natural conditions. There has been a concurrent decrease in turtle-capture success, perhaps due to lesser visitation to the effluent site where nets are tended. Seasonal catch-per-unit-effort declined from a high of 4.14 turtles per monitoring day, to a nine-year low of 1.33 during the 2010–2011 season. It is already apparent that management decisions related to energy policy are affecting the habitat and behavior of this stock of endangered turtles. Green turtles are expected to remain in the San Diego Bay after the SBPP becomes inoperative and continuing research will monitor future impacts and distribution shifts resulting from the expected changes in thermal pattern within south San Diego Bay. Research efforts to study this population (i.e., capture methods and locations) will require modification in response to these changes. Lessons learned here are applicable to the immediate coastal development of San Diego, as well as at similar interactions between marine turtles and industrial thermal effluent discharge throughout Southern California, the United States, and beyond.*

Keywords *Chelonia mydas*, endangered species, once-through cooling, policy, power plant, thermal effluent

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Introduction

Understanding the thermal and structural environmental impacts of coastal development and electrical generating facilities is vital for marine resource management and conservation (Barnett 1971; Langford 1990; Laist and Reynolds 2005a; Halpern et al. 2008). Multiple coastal industries line waterfronts within the United States, and substantial attention from local, state, and federal agencies has been given to the protection of coastal resources and habitats in these areas (Inman and Brush 1973; Proffitt et al. 1986; Brown and McLachlan 2002). This has resulted in increasing emphasis on biological research and monitoring on the living marine resources impacted by these industrial activities, particularly large vertebrates such as marine turtles.

Among the highest profile coastal developments are industrial power plants that use once-through-cooling (OTC) technology that pulls water in from the ocean, a bay, or a river to remove excess heat during the electricity-generation process before being flushed back into the surrounding water body. Currently, 550 OTC power plants operate in the United States, resulting in billions of liters of water being cycled through power plants daily for cooling. Along California's Pacific coast, 19 OTC power-generating facilities provide electricity for coastal cities' residents and businesses, where over half of the state's nearly 37 million residents live (California Energy Commission 2005; U.S. Census Bureau 2009). The southern-most of these plants is the South Bay Power Plant (SBPP), located along the extreme southern shores of San Diego Bay, a site of shallow water and low mixing.

OTC power plants have been shown to dramatically alter the thermal profile of adjacent waters, and their intake systems have the potential to entrain and impinge large numbers of marine animals of all sizes (Sadler 1980; California Energy Commission 2005; Poorima et al. 2006; Newbold and Iovanna, 2007; Chuang, Yang, and Lin 2009). This has resulted in heightened efforts by environmental protection groups to limit impacts and often, mandate large-scale mitigation efforts by offending OTC power plants. For example, the impingement of fish eggs, larvae, and other zooplankton and small vertebrates by the cooling water systems of power plants like the San Onofre Nuclear Generating Station (SONGS) in San Clemente, California necessitated the long-term multimillion dollar SONGS Marine Mitigation Plan (Southern California Edison 2010).

Whereas OTC is largely viewed in a negative sense, this antiquated technology may also have unforeseen positive benefits to coastal organisms. In Florida, for instance, endangered Florida manatees (*Trichechus manatus latirostris*) congregate at warm-water effluent channels of power plants, especially during winter months, and this warm water source has been deemed essential for manatee survival (Irvine and Campbell 1978; Laist and Reynolds 2005b; Edwards et al. 2007; Deutsch, Self-Sullivan, and Mignuci-Giannoni 2008). Similarly, marine turtles aggregate near St. Lucie Nuclear Power Plant in Florida, a study site since the 1970s where researchers have had constant access to multiple species of marine turtles aggregating in the effluent areas (Proffitt et al. 1986; Bresette, Gorham, and Peery 1998).

In San Diego Bay, California, individuals from a resident population of green turtles (*Chelonia mydas*) frequent the warm-water effluent discharge channel of the South Bay Power Plant (Stinson 1984; Dutton and McDonald 1992; Eguchi et al. 2010). OTC-derived warm waters of San Diego Bay allow the green turtles to be active year-round (Eguchi et al. 2010). As part of the Pacific Mexican nesting population, the turtles in San Diego Bay are listed as endangered and are protected under the U.S. Endangered Species Act (ESA) of 1972. Whereas multiple California OTC plants have ESA Section 10 Incidental Take Permits and records of impingement of both green and loggerhead sea turtles (*Caretta caretta*), there have been no impingements of any marine turtles at the SBPP. On the contrary, green turtles aggregate in the warm water effluent and their presence affords researchers a unique opportunity to study this population.

Human activities and developments within the bay and along the coastline are subject to increased scrutiny (i.e., ESA mandated Section 6 and Section 7 consults), and ongoing efforts to study the green turtles in this bay are intended to help managers learn how to mitigate these impacts as they relate to the turtles (National Marine Fisheries Service & U.S. Fish and Wildlife Service, 1998; Komoroske et al. 2011). However, as the energy-production climate in California has evolved in recent years, the need for the OTC energy production in San Diego Bay has decreased to the extent that this 50-year-old power plant will close permanently. In May 2010, the California Legislature approved policy to eliminate all OTC technology by 2020.

In this study, we explore the relationship between energy production, water temperature, and endangered species research. Specifically, we compare success rate in capturing green turtles near the power plant's effluent in relation to SBPP operating level, and illustrate how changes in energy production affect ESA-mandated research on green turtles in San Diego Bay. These findings are then related to local and regional energy policy and environmental assessments for coastal development. We hope that this example provides a framework with which to characterize similar interactions at these and other sites worldwide.

Methods

Study Site

San Diego Bay is 25 km long and 3 km at its widest point. The bay has 87 km of coastline and contains 4,262 ha of open water and 1,788 ha of tidelands (Merkel & Associates, 2008). Shipping channels in the North Bay are significantly deeper (23+ m) than the much shallower South Bay, which averages <5 m below mean lower low water (MLLW) (Figure 1) (U.S. Navy & Port of San Diego 2007; Merkel & Associates 2008). Marine habitats include eelgrass (*Zostera marina*) beds and mud- and sandy-bottom areas interspersed with assemblages of marine algae and invertebrates. These, in addition to marshy wetlands, provide food and shelter for many species of fish, invertebrates, birds, mammals, and reptiles (U.S. Navy & Port of San Diego 2007).

The South Bay Power Plant (SBPP) is at the southern-most end of the bay (Figure 1), located ca. 4 km from the U.S.–Mexico border. This plant began operating in 1960, and when operating at full capacity, it is capable of producing over 700 megawatts (MW) of energy at a moment in time for Southern California residents. Using OTC, the power plant discharges warmed water into the San Diego Bay. Burning natural gas, the SBPP's four steam-powered OTC generating units may use up to 2275 million L (601 million gallons) of seawater per day if operating at maximum level (State Water Resources Control Board 2009). A 2.1-km long earthen dike separates the intake from the discharge channel in effort to minimize mixing of the cooler intake water and the warmed effluent (Figure 1).

Turtle Capture

From 2002–2011, green turtles were captured as part of a long-term study to monitor population size and growth rates. This effort has been ongoing since the 1980s (Dutton and McDonald 1990; Eguchi et al. 2010); however, high-efficiency entanglement nets have been

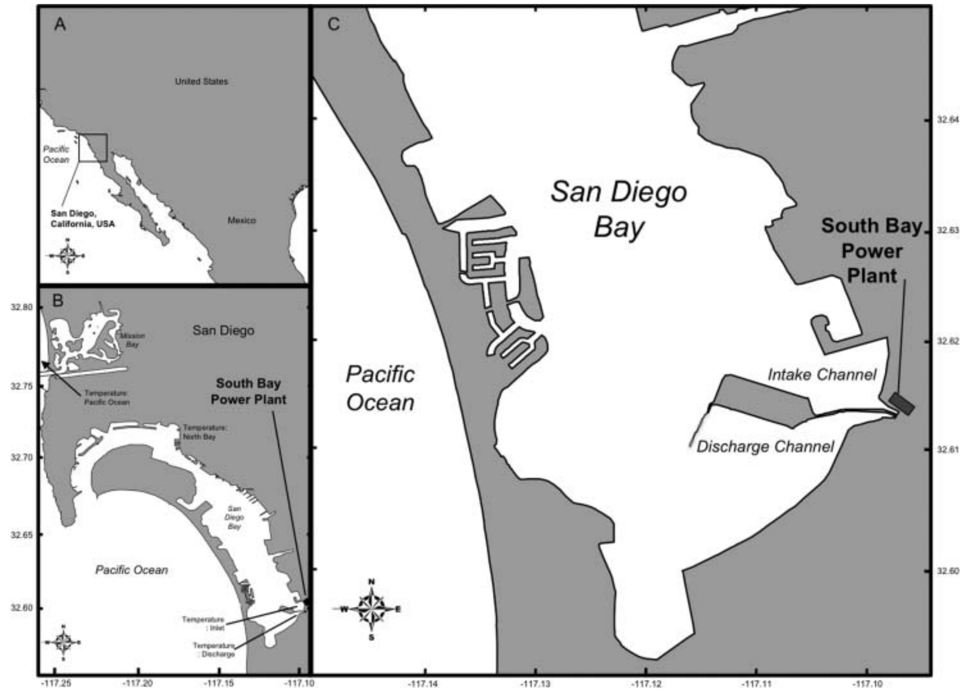

Figure 1. Study site: South Bay Power Plant in San Diego Bay, San Diego, California, USA. A) San Diego, California, United States. B) San Diego Bay. C) South Bay Power Plant.

employed only since 2002. During this period, capture efforts have occurred a maximum of twice a month from November to May, depending on logistics and weather, with nets deployed at various locations throughout the discharge channel (Figure 1). Each net had 50-cm mesh (stretched) and measured ca. 6 m deep and up to 100 m in length; individual net-soak time ranged from 3 to 5 hours. Upon capture, turtles were promptly disentangled and transported to shore ($<$1 km) where they were processed (e.g., morphometric and general health assessment, identification, and tagging), then released within 2 hours. Turtles were identified by a uniquely coded external flipper tag (Inconel #681, National Band and Tag Company, Newport, KY) and/or passive integrated transponder (PIT) tag (AVID, Norco, CA) inserted into the right front flipper.

Annual and daily catch-per-unit-effort (CPUE) was calculated for each field season from 2002–2011. Each field day, a minimum of two 100-m nets were set for a minimum of three hours, and therefore, one unit effort for a daily CPUE could be calculated using net-soak time and total turtles captured during that field day. However, variation in daily net-soak time due to uncontrollable external factors such as tidal conditions, weather and net conditions made net-soak time a less precise measure of effort, and therefore we use "field day" as the unit effort to calculate daily CPUE. On each outing, multiple observers scanned the effluent channel for surfacing turtles, and the particular location of sighted turtles would dictate where the net(s) were deployed. This consistently high level of target based deployments, coupled with placement of nets in standardized locations, suggests that the same maximum effort was invested on every field day. For pooled annual CPUE, one unit effort is equal to the total number of turtles captured that season, divided by total field days during that season. For each season from 2002–2011, daily CPUE for each field day is provided in addition to the number of days in which CPUE = 0.

Habitat Monitoring

To characterize the habitat alterations (i.e., sea surface temperate, SST) caused by the SBPP, we analyzed SST data (0–1 m depth) provided by the SBPP that had been collected once a week at noon (PST) at both the discharge and intake channel. Additional SST data were collected from NOAA's National Data Buoy Center's (NDBC) Station SDBC1 and Station 46231, located in the North Bay and 11.3 km-offshore, respectively (National Data Buoy Center 2009) (Figure 1). Monthly averages from the years 2002–2009 were used to produce annual trends for these four locations. To compare the difference in temperatures between the inlet and discharge channel during each monitoring season from 2002–2009, the temperature differences for each week from November to May were averaged. Water temperature data were unavailable for the 2010–2011 season. Given that temperature has been identified as the primary attractant for green turtles at our capture location, and is also directly related to the operating capacity of the power plant, SST was focused on as the key factor to correlate with capture success. Furthermore, throughout the course of this the study the capture site (discharge channel) has consistently been characterized as a muddy-bottomed habitat lacking seagrass, algae, or other potential prey (J. Seminoff and P. Dutton, unpubl. data), thus minimizing the possibility that habitat structural factors contributed to changes in capture rate.

When operating at maximum capacity, the SBPP generates ca. 700 MW of energy at a point in time. Yet in the past decade, the plant rarely operated at or near this maximum capacity for sustained periods of time. Daily average energy productions (MW) were provided by the SBPP and coincide with the dates of the intake and discharge channel temperature data (SST). The percent of maximum operating capacity was calculated by dividing the daily average of energy generated (MW) by the maximum possible energy generated (700 MW). To compare operation levels during the monitoring seasons from 2002–2009, the weekly operating capacity from November through May was averaged for each season.

Results

Turtle Capture

From 2002 to 2011, a total of 104 individual green turtles were captured a total of 212 times at locations near the SBPP. Forty-five turtles were caught only once, whereas 59 (57%) were captured at least twice, with maximum number of captures of an individual turtle being 13 ($n = 1$). The total number of turtles captured per season ranged from 31 (2006–2007) to 15 (2005–2006), whereas the pooled annual CPUE ranged from 4.14 turtles/day (2002–2003) to 1.33 turtles/day (2010–2011) (Table 1). The maximum number of field days per season was 15 (2010–2011), and the minimum number of days per season was 7 (2002–2003). Prior to the 2006–2007 season, daily CPUE was always $\geq$1. In the 2006–2007 season, daily CPUE = 0 on three of the 13 days (23%). During the 2007–2008 season, daily CPUE = 0 one out of 11 days (9%), and the 2008–2009 season had the highest number of daily CPUE = 0 days, at five out of 11 days (45%). The 2009–2010 and 2010–2011 seasons had two out of 11 (18%) and six out of 15 (40%) daily CUPE = 0 days, respectively.

Table 1
Summary of green turtle capture efforts in San Diego Bay from 2002 to 2011

Season	2002–03	2003–04	2004–05	2005–06	2006–07	2007–08	2008–09	2009–10	2010–11
Field days	7	8	9	9	13	11	11	11	15
Turtles Captured	29	26	29	15	31	27	16	19	20
Min–Max Daily CPUE (turtles/day)	1–10	1–7	1–8	1–2	0–5	0–5	0–5	0–4	0–6
Pooled Annual CPUE (turtles/season)	4.14	3.25	3.22	1.67	2.38	2.45	1.45	1.73	1.33
No. Days CPUE = 0	0	0	0	0	3	1	5	2	6
Field Season Operating Capacity (% of max 700 MW) (Nov–May)	19.7%	27.6%	35.3%	23.5%	7.2%	20.2%	19.6%	*	*
Discharge vs. Inlet Difference (°C)	5.6	6.6	6.9	5.1	1.5	3.7	5.5	*	*

*Data unavailable.

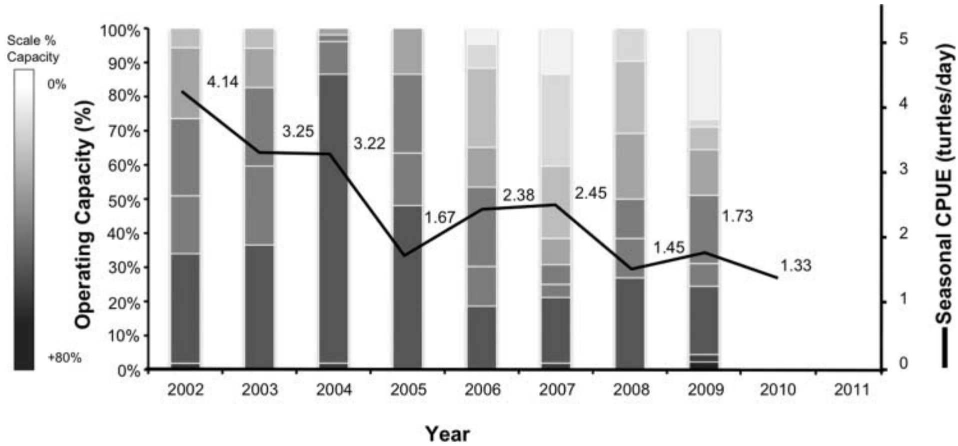

Figure 2. SBPP operating capacity 2002–2009 and seasonal CPUE 2002–2011. Scale represents the percentage of weeks each year in which the plant operated at a specific capacity. 100% Operating Capacity = 700 MW. Seasonal CPUE based on turtles captured per day and averaged over the entire season.

Operational Capacity and Surface Water Temperatures

Between the years 2002–2005, the SBPP's average annual power generation was above 154 MW, or >22% of its maximum operation capacity, peaking at 231 MW (33%) in 2004. The energy produced at the SBPP for the next four years (2006–2009) was less, ranging from 91 MW to 126 MW, or 13 to 18% of maximum operation capacity (Figure 2). Table 1 presents operating capacity during each field season, from November through May during these years.

Sea surface temperature (SST) monitored at the three non-effluent sites had monthly averages that ranged from 12.8 to 18.3°C during winter (December to February), whereas monthly average SST in the discharge channel during the same period ranged from 20.0 to 23.9°C. During the summer months (June–August), the maximum monthly average SST of the coastal ocean water and North Bay was 22.2°C (August), the inlet was 26.4°C (July), and the discharge channel was 31.7°C (August). The maximum SST reading was 38.9°C at the discharge channel in July of 2004 (Figure 3).

After 2004, the number of weeks in which the SBPP generated more than 175 MW of energy (operating above 25% maximum capacity), decreased (Figure 2). When the plant operates at lower levels, less warm effluent is discharged, and the SST of the discharge channel approaches more natural conditions, which more closely track SST at the inlet channel and the rest of the bay (r = 0.9) (Figures 3 and 4). This creates cooler SST conditions near the turtles' aggregation site at the discharge channel (Figure 3).

Discussion

Stinson (1984) first noted that green turtles concentrated in the effluent waters of SBPP, and more recent use of turtle-borne acoustic and satellite transmitters has further confirmed the turtles' heavy use of this area (Dutton and McDonald 1992; Lyon et al. 2006; NOAA unpublished data). The low wintertime SSTs (16–17°C) in areas outside the immediate vicinity of the SBPP, coupled with fact that green turtle activity has been shown to decrease

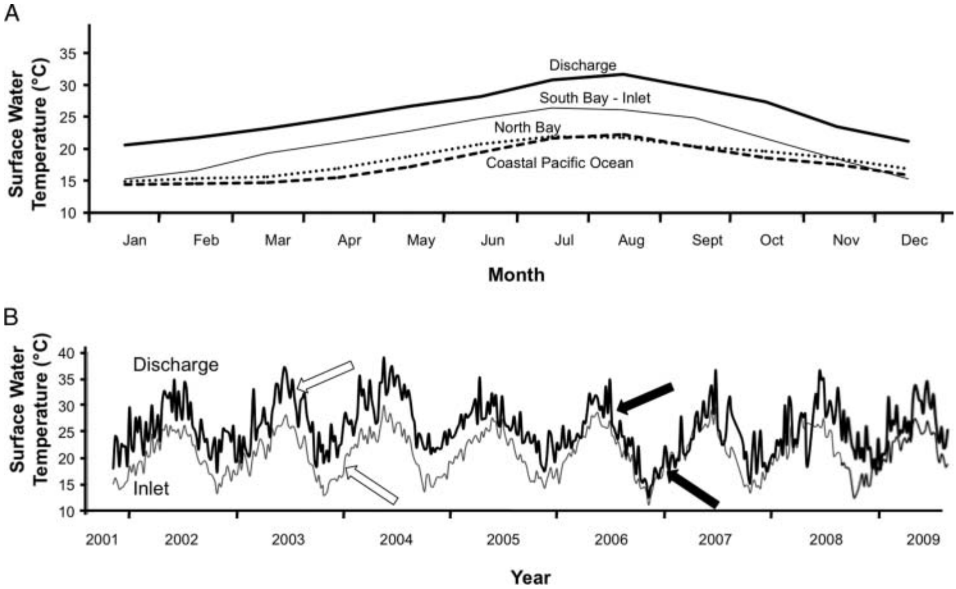

Figure 3. Seasonal trends. A) Seasonal trends: The Coastal Pacific Ocean waters are typically much cooler year round as compared to the water in the San Diego Bay. The Discharge water is typically much warmer year round than the South Bay - Inlet, North Bay, and the Pacific Ocean. B) Annual trends: Open arrows show periods of distinct temperature difference between inlet and discharge water. Closed arrows show periods of little to no temperature difference between inlet and discharge water.

in waters cooler than 18°C (Seminoff 2000; Godley et al. 2002; Hochscheid et al. 2007), suggest that wintertime activity of green turtles in San Diego Bay is directly linked to their ability to access the warm effluent waters of the SBPP. Similarly, during the summer, the extremely high SST (38.9°C) suggests that turtles likely vacate the discharge channel and perhaps the entire effluent-impacted portion of the south bay.

Over the course of this study there has been a clear decrease in effluent output and a commensurate decline in mean water temperature near the SBPP. In December of 2009, two of the four units were permanently taken offline. From 2002 to 2011, there has also been a marked decline in capture success of green turtles within the study area (Figure 1). While it is not possible to draw an unequivocal relationship between decreasing SST and CPUE, we believe these two elements are closely linked. During 2002–2011, the last five seasons had daily CPUE = 0, which had not occurred prior to the 2006–2007 season. Whereas these results show operating capacity does impact CPUE, it is not the only influencing factor. Variables such as air temperature, rainfall, and large-scale climate and oceanographic patterns may have influenced the capture per unit effort; however, these findings suggest that the success of green turtle capture is linked to the SBPP operating level. Given this relationship, the operation level of the plant, especially if it varies, needs to be considered when studying and managing this population of turtles.

Our measurement of CPUE values in this study are not intended to be applied to the derivation of population size, but rather to evaluate the viability of our capture techniques and study sites for monitoring the local green turtle population. We acknowledge that CPUE may also be affected by a decline in the number of turtles within the bay, and/or

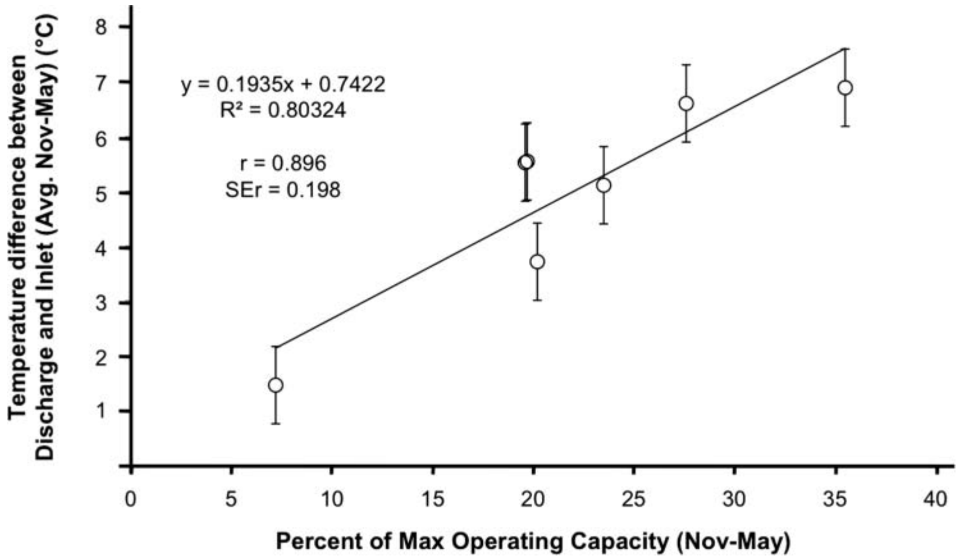

Figure 4. SBPP Operating level and difference in SST between discharge and inlet. Sea surface temperature (SST) difference is the difference between the average temperature during the turtle monitoring season (November–May) of the inlet channel, which more closely resembles the SST of the rest of the San Diego Bay, and the average temperature of the discharge channel during the same period which receives warmed effluent from the power plant. The percent of maximum operating capacity is the average capacity of the power plant divided by the possible maximum output (700 MW), and is directly related to the amount of energy generated during the same monitoring season.

behavioral changes of turtles in response to our capture method. Yet recent population modeling (Eguchi et al. 2010) indicates that the population has remained stable over this time frame. Furthermore, the study site in the effluent-discharge channel is characterized by high turbidity and low visibility that make deployed nets difficult to see in the water. Indeed, a high proportion of turtles in San Diego bay have been recaptured numerous times (Eguchi et al. 2010), suggesting that trap avoidance behavior is minimal.

A distributional shift in green turtle habitat use as a result of changing effluent patterns from the SBPP is the most likely scenario explaining the CPUE decline. Created by the thermal effluent from the SBPP, warmer water (21–22°C) forms a small and distinct refuge for the green turtles, especially during winter months when the rest of the bay is cooler (16–17°C). This area is characterized by shallow depth and residence time of up to 30 days as shown in flow models (Delgadillo-Hinojosa et al. 2007). Combined with the low freshwater input and precipitation characteristic of a Mediterranean-climate, these conditions contribute to much of the SST spatial trend at this site, although the power plant effluent is the dominating influence on local SST. As the SBPP begins to operate at a lower capacity, the distinctive warm water refuge in the discharge channel will no doubt be reduced. This is a significant contributor for the catchability decline, especially considering that all the nets are set in the discharge channel (Figures 1 and 2).

Stinson (1984) originally suggested that all of the turtles left the San Diego Bay during the summer, when the operating SBPP made the water too hot (32–38°C), and returned during the fall when the SBPP provided a refuge in the otherwise cool bay. If this is the case, elimination of the warm water refuge, especially during the winter months, may cause the turtles to react in different ways. Some individuals may seek shallower and warmer areas of the bay, while others may go into winter-dormancy as has been observed of green turtles in northwestern Mexico (Felger, Clifton, and Regal 1976). Similarly, once the SBPP is closed, the water in the south bay will no longer be excessively hot during the late summer months (Figure 3). We have seen no indication that the turtles will completely abandon the San Diego Bay as a foraging habitat with the removal of the SBPP. Indeed the Pacific coast lagoons of Baja California host large numbers of green turtles year round, even during the coldest periods (Lopez-Mendilaharsu et al. 2005).

The amount of energy generated by the SBPP is dictated by the electricity demand in San Diego and is based largely on regulatory policy overseen by the state's energy commission and Independent System Operator (ISO). As a result, the SBPP is in the process of being phased out, and in recent years, the plant has been running at less and less of its operating capacity. For example, the SBPP averaged 35% of its maximum capacity during the 2004–2005 season, dipped to a low of 7% in 2006–2007 and remained below 20% in 2008–2009 (Table 1). This trend in decreasing operation continued following the permanent closure of two of the SBPP's four energy-generating units in 2009, and will continue with the closure of the entire plant. Given the decreasing CPUE observed over the past nine seasons and the increase in daily CPUE = 0 events, the green turtles in the San Diego Bay already appear to be adjusting to the reduced warm-water effluent.

Throughout the world, power plants utilizing OTC technology are either being converted to other cooling processes (i.e., dry cooling) or decommissioned, thus eliminating any warm-water refuge created by OTC effluent. Likewise, industrial steel and paper plants, for example, which also discharge thermal effluent creating similar ecosystem-impact situations around the world, are being dismantled. As technological improvements eliminate the constant input of warmed water, these microhabitats, many which have been sustained for over 50 years, will cease to exist. As these changes occur, concerns over the well-being of the ecosystems and animals that have become dependent on artificially created warm-water habitats will affect policy and complicate decisions for plant operators and the overseeing local and federal agencies. Laist and Reynolds (2005b) acknowledge these challenges confronting policymakers in regards to the survival of endangered manatees in Florida. The temporary closure of one OTC plant where endangered manatees regularly congregate resulted in the multiple mortalities (Packard et al. 1989).

In some instances power plants have had to adopt specific management practices in response to significant negative impacts. For example, some power plants in the southeast United States have been mandated to sustain effluent discharge for the purpose of maintaining optimal manatee habitat (Irvine 1983; Laist and Reynolds 2005b; Florida Fish and Wildlife Conservation Commission 2008). Specifically, Florida Light & Power Company operates five coastal plants and implements required manatee protection plans (Marine Mammal Commission 2003; Florida Fish and Wildlife Conservation Commission 2008). Different from Florida's manatees, sustaining warm water effluent from the SBPP for San Diego's green turtles is less critical. Multiple turtle species exhibit behavioral and physiological adaptations to cope with cooler environments such as vacating cold waters, hibernating, or overwintering (Hochscheid et al. 2005; Ultsch 2006). Green turtles in the Gulf of California have been shown to go into torpor when SST falls below 15°C (Felger, Clifton, and Regal 1976) and loggerheads in Florida have been observed in a similar state (Carr, Ogren, and McVea 1980). In San Diego Bay, the SST regularly falls to 15°C in the winter months (December and January). Yet the SBPP effluent has kept the discharge channel SST above this 15°C threshold, with one exception during 2002–2009 period, in which the SST of the discharge channel was ≤15°C for eight consecutive weeks during the winter of 2006–2007 (December 20, 2006–February 6, 2007). This occasion corresponded with a significant decrease in the SBPP's operating level. (Operating levels during the 2006–2007 winter, from December 20, 2006 to June 19, 2007, averaged 3.8%, with energy output values ranging from 0 to 65.5 MW; compared to the same period the previous year (December 20, 2005 to June 20, 2005) average operating capacity was 19.1% and energy output ranged from 0 to 249.2 MW.) These findings will be useful during the state mandated environmental assessment required for the demolition and later development which will occur at this site once the SBPP is offline.

With the elimination of the SBPP, turtles remaining in the San Diego Bay may hibernate, move to warmer water within the bay, or vacate the bay and move south to warmer areas. The physiological (i.e., ectothermic versus endothermic) and behavioral differences between marine turtles and manatees drive the need for different, albeit related, species management as it pertains to future policy changes impacting coastal OTC power plants. In Southern California, managers at other sites are facing related challenges of marine turtle and power plant interactions. North of the SBPP, the San Onofre Nuclear Power Plant in Carlsbad, CA must minimize and mitigate interaction with multiple marine species, including marine turtles, at the intake and discharge sites of the plant. Further north along the coast, green turtles forage in the brackish Alamitos Bay and the San Gabriel River in Orange County near the AES Southland Alamitos power plant (D. Lawson, pers. comm.). Similar interactions are not unique to California, or the United States. Examples of marine turtle interaction with thermally discharging power and industrial plants exist worldwide. Lessons learned at the SBPP, like those learned at other locations, should be shared to help guide coastal management at large.

Local, Regional, and International Management Applications

Beyond San Diego Bay and sites previously discussed in California and Florida, comparable interactions occur globally. In Northern Chile, multi-year studies found the OTC Mejilones Power Plant near Antofagasta to be one of three key sea turtle congregation sites in the region (Guerra-Correa et al. 2008). Like other coastal power plants, the turtles are presumably attracted to the warmed thermal effluent. At this site, not only are turtles concentrated near the thermal discharge, but South American sea lions (*Otaria flavescens*) have begun preying on marine turtles, complicating the management at this site (Guerra-Correa 2007). At separate locations in central Chile, coastal power plants have been the subject of much debate. Recently the Chilean President halted plans for new coastal power plants in response to anticipated impact to the local marine habitat at Punta de Choros marine preserve (Oceana 2010). These interactions are not limited to OTC power plants, but include industrial plants, such as steel plants. For example, turtles have been monitored in the thermal discharge channel at the Tubarao Steel Company site in Vitoria, Espirito Santo, Brazil (Torezani et al. 2010). Continued development and technological advancements will continue to impact these dynamic coastal ecosystems. Similar management challenges exist at each of these locations where economic progress, environmental conservation, and endangered species protection must be balanced.

The situation at the SBPP parallels what managers at similar sites are or will face in the future. First, as these types of plants age and are decommissioned, the aquatic environment will shift into a completely different regime, where temperature-range shifts may eliminate some ecosystem inhabitants. Studies such as this one will be necessary to monitor the behavioral response and physical condition of marinelife, especially endangered species, as these changes occur. Second, growing populations in coastal cities continue to increase the demand for energy production. Public officials, managers, and local citizens face difficult decisions as to what environmental impacts will be compromised to meet the growing energy demand, while also working to lower per-capita energy consumption. In San Diego, finding a suitable method in which to deliver solar-generated energy, an alternative energy source once the SBPP is closed, continues to be a challenge, as the proposed Sunrise Powerlink transmission line would run through sensitive terrestrial ecosystems (Jones & Stokes 2008; California Public Utilities Commission 2010).

Upon closure of the SBPP, the bay's marine environment will be impacted. Our ability to study this population of endangered green turtles is hampered indirectly by the gradual closure of this OTC power plant. Following the closure of the SBPP, the effluent will be eliminated, the plant will be removed and new development will eventually be erected along the bay's coastline. Knowing what changes may occur to the ecosystem of this urbanized bay and working to anticipate and observe the impacts, especially in relation to protected species and habitats, will help stakeholders in achieving goals of balancing economic growth with environmental conservation. These types of interactions warrant further study, especially as many coastal power plants using OTC technology will begin to be phased out worldwide in the next decade.

Post Script

In October 2010, the ISO reviewed the electricity need for the region and removed the must-run-status for the South Bay Power Plant (California Independent System Operator 2010). The SBPP was shutdown on December 31, 2010; full demolition of the coastal plant likely will not begin until 2012 after required environmental reviews are conducted and approved.

References

Barnett, P. R. O. 1971. Some changes in intertidal sand communities due to thermal pollution. *Proceedings of the Royal Society of London, Series B* 177:353–364.

Bresette, M., J. Gorham, and B. Peery. 1998. Site fidelity and size frequencies of juvenile green turtles, Chelonia mydas, utilizing nearshore reefs in St. Lucie County, Florida. *Marine Turtle Newsletter* 82:5–7.

Brown, A. C., and A. McLachlan. 2002. Sandy shore ecosystems and the threats facing them: Some predictions for the year 2025. *Environmental Conservation* 29 (1): 62–77.

California Energy Commission. 2005. Staff Report CEC-700-2005-013: Issues and Environmental Impact Associated with Once- though Cooling at California's Coastal Power Plants. Available at http://www.energy.ca.gov/2005_energypolicy/documents/index.html#051005 (accessed December 1, 2009).

California Independent System Operator, Keith E. Casey. Letter to Members of the State Water Resources Control Board. October 18, 2010.

California Public Utilities Commission. 2010. San Diego Gas & Electric Company's Sunrise Powerlink Project. Available at http://www.cpuc.ca.gov/environment/info/aspen/sunrise/sunrise.htm (accessed November 1, 2010).

Carr, A., L. Ogren, and C. McVea. 1980. Apparent hibernation by the Atlantic Loggerhead Turtle (*Carretta carretta*) off Cape Canaveral, Florida. *Biological Conservation* 19:7–14.

Chaloupka, M. Y., P. Dutton, and H. Nakano. 2004. Status of sea turtle stocks in the Pacific. FAO Papers presented at the Expert Consultation on Interactions between Sea Turtles and Fisheries within an Ecosystem Context, 135–164. FAO Fisheries Report, Rome.

Chuang, Y., H. Yang, and H. Lin. 2009. Effects of a thermal discharge from a nuclear power plant on phytoplankton and periphyton in subtropical waters. *Journal of Sea Research* 61:197–205.

Delgadillo-Hinojosa, F., A. Zirino, O. Holm-Hansen, J. M. Hernandez-Ayon, T. J. Boyd, B. Chadwick, and I. Rivera-Duarte. 2007. Dissolved nutrient balance and net ecosystem metabolism in a Mediterranean-climate coastal lagoon: San Diego Bay. *Estuarine, Coastal and Shelf Science* 76:594–607.

Deutsch, C. J., C. Self-Sullivan, and A. Mignucci-Giannoni. 2008. Trichechus manatus. In IUCN 2009. IUCN Red List of Threatened Species. Version 2009.1. Available at www.iucnredlist.org (accessed January 3, 2009).

Dutton, P., and D. McDonald. 1990. Sea turtles present in San Diego Bay. In *Proceedings of the Tenth Annual Workshop on Sea Turtle Biology and Conservation*, ed. T. J. Richardson, 139–141. Washington, DC: NOAA Technical Memorandum NMFS-SEFC-278.

Dutton, P., and D. McDonald. 1992. Ultrasonic tracking of sea turtles in San Diego Bay. In *Proceedings of the Twelfth Annual Workshop on Sea Turtle Biology and Conservation*, compilers J. I. Richardson and T. H. Richardson, 218–221. Washington, DC: NOAA Technical Memorandum NMFS-SEFC-361.

Edwards, H. H., K. H. Pollock, B. B. Ackerman, J. E. Reynolds, and J. A. Powell. 2007. Estimation of detection probability in manatee aerial surveys at a winter aggregation site. *Journal of Wildlife Management* 71 (6): 2025–2060.

Eguchi, T., J. A. Seminoff, R. LeRoux, P. H. Dutton, and D. M. Dutton. 2010. Abundance and survival rates of green turtles in an urban environment: Coexistance of humans and an endangered species. *Marine Biology* 157:1869–1877.

Felger, R., K. Clifton, and P. Regal. 1976. Winter dormancy in sea turtles: Independent discovery and exploitation in the Gulf of California by two local cultures. *Science* 191 (4224): 283–285.

Florida Fish and Wildlife Conservation Commission. 2008. *Summary of Artificial Warm Water Refugia Issues*. Available at http://myfwc.com/manatee/habitat/warmwat.htm (accessed December 1, 2008).

Godley B. J., S. Richardson, A. C. Broderick, M. S. Coyne, F. Glen, and G. C. Hays. 2002. Long-term satellite telemetry of the movements and habitat utilization by green turtles in the Mediterranean. *Ecography* 25:352–362.

Guerra-Correa, C. 2007. Sea turtles situation is critical in Mejillones Del Sur Bay in Northern Chile. Letter to Marman Listserve. August 2, 2007. MS. Universidad De Antofagasta, Chile.

Guerra-Correa, C. G., C. M. Guerra-Correa, P. D. Bolados, A. Silva, and P. Garfias. 2008. Sea turtle congregations in discrete temperate shoreline areas in cold Northern Chilean coastal waters. In *Proceedings of the Twenty-Seventh Annual Symposium on Sea Turtle Biology and Conservation*, compilers A. F. Rees, M. Frick, A. Panagopoulou, and K. Willams, 211–212. Washington, DC: NOAA Technical Memorandum NMFS-SEFSC-569, 262 p.

Halpern, B. S., S. Walbridge, K. A. Selkoe, C. V. Kappel, F. Micheli, C. D'Agrosa, J. F. Bruno, et al. 2008. A global map of human impact on marine ecosystems. *Science* 319 (5865): 948–952.

Hochscheid, S., F. Bentivegna, M. N. Bradai, and G. C. Hays. 2007. Overwintering behavior in sea turtles: Dormancy is optional. *Marine Ecology Progress Series* 340:287–298.

Inman, D. L., and B. M. Brush. 1973. The coastal challenge. *Science* 181 (4094): 20–32.

Irvine, A. 1983. Manatee metabolism and its influence on distribution in Florida. *Biological Conservation* 25:314–334.

Irvine, A. B., and H. W. Campbell. 1978. Aerial census of the West Indian mantee, *Trichechus manatus,* in the Southeastern United States. *Journal of Mammology* 59 (3): 613–617.

Jones & Stokes. 2008. Electric Grid Reliability Impacts from Once-Through Cooling in California, Prepared for California Ocean Protection Council and State Water Resources Control Board. April. (J&S 041808) Sacramento, CA. 64 p.

Komoroske, L. M., R. L. Lewison, J. A. Seminoff, D. D. Deheyn, A. K. Miles, and P. H. Dutton. 2011. Pollutants and the health of green sea turtles resident to an urbanized estuary in San Diego, CA. *Chemosphere* doi:10.1016/j.chemosphere.2011.04.023

Laist, D., and J. Reynolds. 2005a. Influence of power plants and other warm-water refuges on Florida manatees. *Marine Mammal Science* 21 (4): 739–764.

Laist, D., and J. Reynolds. 2005b. Florida manatees, warm-water refuges, and an uncertain future. *Coastal Management* 33 (3): 279–295.

Langford, T. E. L. 1990. *Ecological effects of thermal discharges*. London: Elsevier Applied Science.

Lopez-Mendilaharsu, M., S. C. Gardner, J. A. Seminoff, and R. Riosmena-Rodriguez. 2005. Identifying critical foraging habiatats of the green turtle (*Chelonia mydas*) along the Pacific coast of the Baja California peninsula, Mexico. *Aquatic Conservation: Marine and Freshwater Ecosystems* 15:259–269.

Lyon, B., J. Seminoff, T. Eguchi, and P. Dutton. 2006. *Chelonia* in and out of the jacuzzi: Diel movements of East Pacific green turtles in the San Diego Bay, USA. In *Book of Abstracts. Twenty Sixth Annual Symposium on Sea Turtle Biology and Conservation*, compilers M. Frick, A. Panagopoulou, A. F. Rees, and K. Williams. Athens, Greece: International Sea Turtle Society.

Marine Mammal Commission. 2003. Marine Mammal Commission Annual Report to Congress 2002. Marine Mammal Commission. Bethesda, Maryland.

Merkel & Associates. 2008. San Diego Bay Eelgrass Inventory and Bathymetry Update. Unpublished report prepared for US Navy Region Southwest Naval Facilities Engineering Command, San Diego Unified Port District.

National Data Buoy Center. 2009. Station SDBC1—9410170—San Diego, CA. Available at http://www.ndbc.noaa.gov/station_page.php?station=sdbc1 Station 46231—Mission Bay, CA (093). Available at http://www.ndbc.noaa.gov/station_page.php?station=46231

National Marine Fisheries Service and U.S. Fish and Wildlife Service. 1998. Recovery plan for US Pacific populations of the East Pacific green turtle (*Chelonia mydas*). National Marine Fisheries Service, Silver Spring, MD.

Newbold, S., and R. Iovanna. 2007. Population level impacts of cooling water withdrawals on harvested fish stocks. *Environmental Science and Technology* 41 (7): 2108–2114.

Oceana. 2010. Punta De Choros: What Oceana does. *Home | Oceana North America*. August 10. Available at http://na.oceana.org/en/our-work/preserve-special-places/punta-de-choros/what-oceana-does (accessed November 8, 2010).

Packard, J., R. Frohlich, J. Rynolds, and J. Wilcox. 1989. Manatee response to interruption of a thermal effluent. *The Journal of Wildlife Management* 53 (3): 692–700.

Poornima, E. H., M. Rajadurai, V. N. R. Rao, S. V. Narasimhan, and V. P. Venugopalan. 2006. Use of coastal waters as condenser coolant in electric power plants: Impact on phytoplankton and primary productivity. *Journal of Thermal Biology* 31:556–564.

Proffitt, C. E., R. E. Martin, R. G. Ernest, B. J. Graunke, S. E. LeCroy, K. A. Muldoon, and B. D. Peery. 1986. Effects of power plant construction and operation on the nesting of the loggerhead sea turtle (*Caretta caretta*): 1971–84. *Copeia* 3: 813–816.

Sadler, K. 1980. Effect of warm water discharge from a power station on fish populations in the river Trent. *Journal of Applied Ecology* 17:349–357.

Seminoff, J. A. 2000. Biology of the East Pacific green turtile, *Chelonia mydas agassizii*, at a warm temperate feeding area in the Golf of California, Mexico. PhD diss., The University of Arizona, Tuscon, AZ.

Seminoff, J. A., T. T. Jones, A. Resendiz, W. J. Nichols, and M. Y. Chaloupka. 2003. Monitoring green turtles (*Chelonia mydas*) at a coastal foraging area in Baja California, Mexico: multiple indicies to describe population status. *Journal of Marine Biological Association of the United Kingdom* 83 (6): 1355–1362.

Southern California Edison. 2010. *SCE Marine Mitigation*. Available at http://www.sce.com/PowerandEnvironment/PowerGeneration/MarineMitigation/

State Water Resources Control Board. 2009. *San Diego Region Tenative Fact Sheet*. San Diego: RWQCB.

Stinson, M. 1984. *Biology of sea turtles in San Diego Bay, California, and in the north eastern Pacific Ocean*. San Diego State University. San Diego: Master's Thesis.

Torezani, E., C. Baptistotte, S. L. Mendes, and P. C. R. Barata. 2010. Juvenile green turtles (*Chelonia mydas*) in the effluent discharge channel of a steel plant, Espírito Santo, Brazil, 2000–2006. *Journal of the Marine Biological Association of the United Kingdom*, 90, 233–246. doi:10.1017/S0025315409990579.

Ultsch, G. R. 2006. The ecology of overwintering among turtles: where turtles overwinter and its consequences. *Biological Reviews*, 81(3): 339–367.

U.S. Census Bureau. 2009. 2009 population estimates, Census 2000, 1990 Census. Available at http://factfinder.census.gov

U.S. Navy and Port of San Diego. 2007. *The San Diego Bay Integrated Natural Resouces Management Plan–Draft–The State of the Bay—Natural resources and human uses*. San Diego: US Navy.