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VENOUS BLOOD GASES AND LACTATES OF WILD LOGGERHEAD SEA TURTLES (*CARETTA CARETTA*) FOLLOWING TWO CAPTURE TECHNIQUES

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ABSTRACT: During summer of 2001, venous blood gases were determined in loggerhead sea turtles (*Caretta caretta*) captured by trawl ($n=16$) in coastal waters of South Carolina and Georgia (USA) as part of a sea turtle census program and captured in pound nets ($n=6$) in coastal North Carolina (USA) during a study of sea turtle population biology. Trawls were towed for 30 min, so turtles captured were forcibly submerged for ≤30 min. Pound nets are passive gear in which fish and sea turtles are funneled into a concentrated area and removed periodically. Sea turtles in pound nets are free to surface and to feed at will. Blood was obtained from the dorsal cervical sinus as quickly as possible after landing on the boat (range 2–10 min trawl, 1–2 min pound net) and at 30 min after landing just prior to release. Blood gases including pH, partial pressures of O_2 and CO_2 (pO_2, pCO_2), and lactate were measured within 10 min. Instrument measurements for pH, pO_2, and pCO_2 made at 37 C were corrected to cloacal temperature and HCO_3^- was calculated from temperature-corrected pH and pCO_2. Venous blood pH and bicarbonate were higher, and pO_2 and lactate were lower from pound net-captured turtles compared to trawl captured turtles at the initial sampling time. In pound net turtles, pH and bicarbonate declined and lactate increased during 30 min on deck. In trawled sea turtles, venous blood pH increased and pCO_2 and pO_2 decreased during the 30 min on deck. Both capture systems caused perturbations in blood gas, acid-base, and lactate status, though alterations were greater in trawl captured turtles.

Key words: *Caretta caretta,* lactate, loggerhead sea turtle, pound net, trawl, venous blood gases.

INTRODUCTION

Sea turtles are subject to incidental capture in a variety of fisheries with different primary target species (Epperly, 2003). A study team mandated in 1988 by the US Congress identified shrimp trawls as the major cause of human-associated mortality, with as many as 44,000 sea turtles killed annually by the US fleet (Magnuson et al., 1990). Implementation of turtle excluder device (TED) regulations phased in from 1989–94 in US waters has been credited with decreasing sea turtle strandings on South Carolina and Georgia (USA) beaches by 37–58% (Epperly, 2003). Currently, shrimp trawlers in nearly all US inshore and offshore waters south of Cape Hatteras, North Carolina (USA), are required to be fitted with TEDs year-round, and certain other trawl fisheries impacting sea turtle populations are required to have TEDs at specified times and locations. Exemptions to TED requirements are allowed temporarily when tropical storms result in substantial debris that can clog TEDs and for an extended period in an area of North Carolina where dense algae interferes with TED operations and compliance with limitations on tow times can be monitored by shore-based observers (Epperly, 2003). Additionally, currently used TEDs are too small to allow escape from the net by larger loggerhead (*Caretta caretta*), green (*Chelonia mydas*), and leatherback (*Dermochelys coriacea*) sea turtles (Epperly and Teas, 2002), a situation currently under regulatory review. By contrast, another commercial fishing gear with frequent incidental sea turtle catch, but considered to

cause minimal mortality, is the pound net (Oravetz, 1999). Pound nets are fixed gear used in shallow protected waters and target various finfish. They are composed of a long straight leader net which directs fish towards a funnel and into a smaller holding net (the pound). From the pound, the fisherman periodically collects the live catch, and bycatch can be sorted out more selectively than for many other gear types. Sea turtles also become entrapped, but while in the pound are free to breathe and feed at will, so that forced submergence and mortality are uncommon. Mesh sizes typically used are small enough to minimize sea turtle entanglement, though this does cause occasional mortalities, particularly with larger mesh size and slack leads (Oravetz, 1999). Both trawl and pound net gear types are used by sea turtle biologists for capture of study animals (Epperly et al., 1995; Segars et al., 2001).

Sea turtle blood gases and acid/base balance in response to voluntary and forced submergence have received considerable attention (Berkson, 1966, 1967; Hochachka et al., 1975; Butler et al., 1984; Lutz and Bentley, 1985; Lutz and Dunbar-Cooper, 1987; Lutcavage and Lutz, 1991, 1997; Stabenau et al., 1991). Findings of severe lactic acidosis with forced submergence and, more critically, direct assessment of trawl tow time effects on sea turtle survival (Henwood and Stuntz, 1987) have led to tow time restrictions on permitted shrimp trawls not equipped with TEDs in specified fisheries in restricted regions (e.g., 55 min tow times from 29 June–31 October, 75 min tow times 1–30 November, Proclamation SH-6–2002, North Carolina Division of Marine Fisheries).

Prior studies of sea turtle blood gases have primarily taken place in laboratory settings, constrained by availability of blood gas analyzer equipment or necessity of maintaining arterial or cardiac catheters. One study of venous blood gases in sea turtles subjected animals to trawling under field conditions, but utilized captive-reared animals placed directly into the trawls, resulting in forcible submergence for ≤7.3 min (Stabenau et al., 1991). Recent development of portable blood gas analyzer technology (iStat Portable Clinical Analyzer, Heska Corporation, Fort Collins, Colorado, USA) permits blood gas and lactate measurement of wild well-conditioned sea turtles captured in functioning fishing gear of various types. In this study we examined loggerhead sea turtle venous blood gas, pH and lactate response, and 30 min on-board recovery following capture by trawl net, which involves forcible submergence, and by pound net, which does not.

MATERIALS AND METHODS

Loggerhead sea turtles ($n=16$) were captured by trawl from 12 June–2 July 2001 in South Carolina and Georgia in conjunction with ongoing studies of sea turtle population biology (Segars et al., 2001). Turtles were collected by fishery independent trawlers operating in near-shore waters between Winyah Bay, South Carolina (33°10′N, 79°10′W) and St. Augustine, Florida (USA; 29°50′N, 81°15′W) in 4.5–12.2 m deep water. Water temperature ranged from 25.6–29.7 C. Trawlers used 20 m four-seam nets with 20 cm mesh, without TEDs. Trawl duration was limited to 30 min. Weight and straight carapace length (SCL) of the turtles were measured on board.

Additional loggerhead sea turtles ($n=6$) were captured from 13–25 August 2001 in actively-fished pound nets in Core Sound near Atlantic, North Carolina (34°55′N, 76°20′W) in 0.6–2.4 m deep water in conjunction with studies of sea turtle species composition and demography (Epperly et al., 1995). Water temperature ranged from 27.1–29.2 C. Pound nets were checked by the fisherman three times weekly, so the maximum time spent in the pound net by any given turtle would have been 3 days. Straight carapace length of the turtles was measured on board, but weight was determined only on those turtles small enough to be brought to shore.

For both capture methods, turtles were variously restrained manually, in carrier crates, or elevated on automobile tires to restrict movement on deck. No visible adverse effects of capture were noted during the holding period and all turtles swam away vigorously upon release.

During trawl operations blood gas analysis

was conducted only when turtles were captured singly. During pound net captures turtles could be removed from the water sequentially, and overlap of processing occurred for two turtles from two different nets. Blood was collected as soon as practical after the turtles were brought on board and 30 min after the initial sampling. The time interval between bringing the turtle on board until blood was collected was recorded. Venous blood was collected from the dorsal cervical sinus into heparinized 3 ml syringes fitted with 22 ga 0.7×40 mm needles. Needles were stoppered and syringes kept inside a cooler on cold packs until blood gas analysis within 10 min of blood collection. Cloacal temperature was measured initially when possible, and at 30 min after capture (Digi-Sense Thermocouple Thermometer Type T, Cole-Parmer Instrument Company, Vernon Hills, Illinois, USA). When not possible to obtain an initial cloacal temperature (pound net captures), water temperature was held to represent turtle temperature. In cases where both cloacal and water temperature were obtained, the cloacal temperature was a median 0.4 C warmer than water temperature (range 0.5–1.8 C, $n=16$). Respiratory rates were measured initially and at 30 min after capture for trawl captures and at 30 min after capture for pound net captures, but it was not possible to obtain an initial respiratory rate in the actively fishing pound net boat.

Blood gas analysis was performed on board using the iStat Portable Clinical Analyzer (Heska Corporation, Fort Collins, Colorado, USA) with CG4+ cartridges. Analytes measured were pH, partial pressure of O_2 and CO_2 (pCO_2, pO_2), and lactate. The iStat instrument performs analysis of samples at 37 C, then corrects for patient temperature by human-based algorithms. Bicarbonate, oxygen saturation, and base excess are calculated by the instrument from directly-measured values. Temperature corrections for sea turtle blood gases were, therefore, performed as follows, rather than according to the algorithms encoded in the iStat (Chittick et al., 2002). Corrections for pH were performed with the formula, $pH_{corr}=pH_{37\,C}+0.014\times(T\,C)$, which incorporates the pH/T value of 0.014 U/C determined for green sea turtles in the 25–35 C temperature range (Kraus and Jackson, 1980). Corrections for pCO_2 were made with the formula $pCO_{2\,corr}=pCO_{2\,37\,C}\times10^{(-0.019[T\,C])}$ (Ashwood et al., 1983); this is equivalent to the iStat formula. Temperature corrected pH and pCO_2 values were used to calculate bicarbonate via the Henderson-Hasselbalch equation, $HCO_3^-=\alpha CO_2\times pCO_{2\,corr}\times10^{(pHcorr-pKa)}$ (Stabenau and Heming, 1993). Values for αCO_2 and pKa were calculated or determined graphically based on temperature and temperature-corrected venous pH for each turtle, using equations and graphs derived empirically from Kemp's ridley (*Lepidochelys kempii*) plasma (Stabenau and Heming, 1993). Values ranged from 0.0358–0.0400 for αCO_2 and from 6.142–6.160 for pKa. Estimates for pO_2 were calculated from the formula $pO_{2\,corr}=pO_{2\,37\,C}\times10^{(-0.0058\,[TC])}$ (Ashwood et al., 1983).

Data were tested for normal distribution by the Shapiro-Wilk W test (3.0.2, SAS Institute Inc., Cary, North Carolina, USA). Because some data are not normally distributed, summary statistics are reported as median, lower, and upper quartiles and range, and nonparametric methods of comparison are employed. Comparisons between groups were made by Wilcoxon rank sum test for two groups or Kruskal-Wallis test for three or more groups followed by Dunn's multiple comparison test (Hollander and Wolfe, 1973). Comparisons within groups at initial and 30 min time points were made by Wilcoxon matched pairs signed ranks test. Correlation between lactate and bicarbonate, for all turtles including both sampling times, was tested using Kendall tau b, as was correlation between weight and initial venous lactate for trawl-captured turtles. Trends within time of landing to time of blood collection for trawl captures were tested by one-way analysis of variance (ANOVA). Sample sizes represented in the analyses were 16 turtles captured by trawl and six turtles captured by pound net for all measured analytes at both sampling times, except for lactate, due to sporadic failure of the clinical analyzer to register lactate values. For trawl captures, 11 lactate values were obtained at the initial sampling time and 13 at 30 min; for pound net captures, five lactate values were recorded for both the initial and 30 min sampling times. Statistical significance was set at $P<0.05$.

RESULTS

Median (lower quartile, upper quartile; range) weight of 19 loggerhead sea turtles was 45.5 (36.3, 61.4; 21.0–136) kg, and SCL of 21 loggerhead sea turtles was 64.7 (59.4, 72.6; 50.2–92.5) cm. No significant difference in SCL was detected between collection methods (Wilcoxon rank sum test, $n=6$ pound net captures, $n=15$ trawl captures [SCL not obtained for one trawl capture], $P=0.46$). Because the three largest turtles were released from pound nets without weighing, weights were not com-

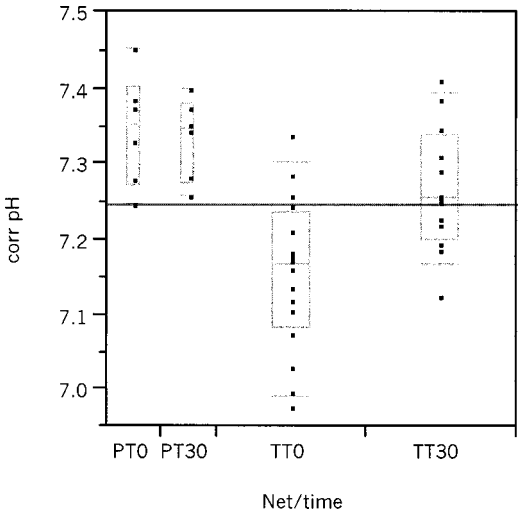

FIGURE 1. Temperature corrected venous pH of loggerhead sea turtles immediately following capture by pound net (PT0) or trawl (TT0) and after 30 min on deck (PT30 and TT30 for pound net and trawl, respectively). Quantile boxes show the nonparametric measures of dispersion: the 10th, 25th, 50th (median), 75th, and 90th quantiles; the horizontal line indicates the total response sample mean. X-axis is proportional to sample size (n=6 for pound net, n=16 for trawl). Venous pH was significantly lower from loggerheads captured by trawl at T_0 than for any other group.

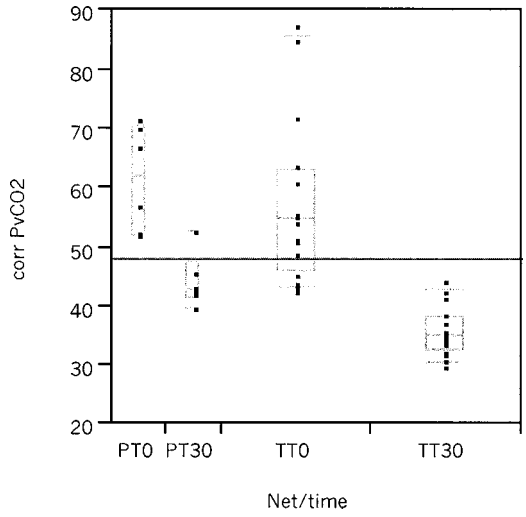

FIGURE 2. Temperature corrected $PvCO_2$ (in mmHg) of loggerhead sea turtles immediately following capture by pound net (PT0) or trawl (TT0) and after 30 min on deck (PT30 and TT30 for pound net and trawl, respectively). X-axis is proportional to sample size (n=6 for pound net, n=16 for trawl). $PvCO_2$ values were significantly less at 30 min than initially for both pound net and trawl captures.

pared between collection methods. Water temperature and initial and final cloacal temperatures did not differ significantly between collection methods (Kruskal-Wallis test, P=0.89), and initial and final cloacal temperatures did not differ significantly within groups (Wilcoxon matched pairs signed rank test, P=0.62 for trawl and 0.31 for pound net).

Respiratory rates did not differ significantly between trawl T_0, trawl T_{30} and pound net T_{30} groups (Kruskal-Wallis test, P=0.08), though respiration was more rapid in all groups (trawl T_0, median 5.2, range 1.0–10 breaths/min; combined pound net and trawl T_{30}, median 3.0, range 1.0–4.2 breaths/min) than reported respiratory rates of captive swimming unrestrained subadult loggerheads at 22–25 C (0.34 breaths per min; Lutcavage and Lutz, 1991) and immature green sea turtles at 25 C (0.65 breaths/min; Kraus and Jackson, 1980).

Temperature corrected venous blood gas and lactate results are shown in Figures 1–5. Venous pH (Fig. 1) was significantly lower from loggerheads captured by trawl at T_0 than for any other group (Kruskal-Wallis test, P=0.0002; Dunn's multiple comparison test, P<0.05). Partial pressure of CO_2 in venous blood ($PvCO_2$) values (Fig. 2) were significantly less at 30 min than initially for both pound net and trawl captures (Kruskal-Wallis test, P<0.0001; Dunn's multiple comparison test, P<0.05). Partial pressure of O_2 in venous blood (PvO_2) (Fig. 3) was significantly greater for trawl captures at T_0 than for any other group (Kruskal-Wallis test, P=0.0033; Dunn's multiple comparison test, P<0.05). Bicarbonate (Fig. 4) declined significantly following 30 min on deck for both pound net (T_0 median [quartiles; range] 35.0 [32.7, 41.5; 32–43] mmol/l, T_{30} 26.5 [21.2, 29.2; 19–30] mmol/l; Wilcoxon matched pairs signed ranks test, P=0.031) and trawl

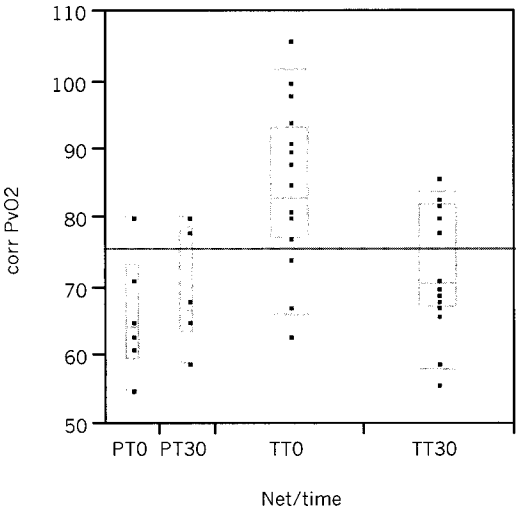

FIGURE 3. Temperature corrected PvO_2 (in mmHg) of loggerhead sea turtles immediately following capture by pound net (PT0) or trawl (TT0) and after 30 min on deck (PT30 and TT30 for pound net and trawl, respectively). X-axis is proportional to sample size (n=6 for pound net, n=16 for trawl). PvO_2 was significantly greater for trawl captures at T_0 than for any other group.

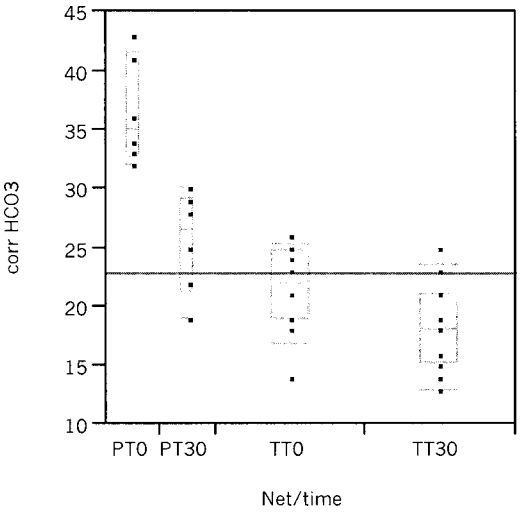

FIGURE 4. Bicarbonate (in mmol/l) calculated from corrected pH and $PvCO_2$ of loggerhead sea turtles immediately following capture by pound net (PT0) or trawl (TT0) and after 30 min on deck (PT30 and TT30 for pound net and trawl, respectively). X-axis is proportional to sample size (n=6 for pound net, n=16 for trawl). Bicarbonate declined significantly following 30 min on deck for both pound net and trawl captures, and both started and ended significantly lower for trawl captures than pound net captures.

captures (T_0 22.0 [19.0, 24.7; 14.0–26.0] mmol/l, T_{30} 18.0 [15.2, 21.0; 13–25] mmol/L; Wilcoxon matched pairs signed ranks test, $P<0.001$), and both started and ended significantly lower for trawl captures than pound net captures (Kruskal-Wallis test, $P<0.0001$; Dunn's multiple comparison test, $P<0.05$). Lactate values (Fig. 5) were significantly greater in pound net captures at 30 min (9.5 [6.2, 13.6; 4.0–14.8] mmol/l) than initially (1.3 [1.0, 3.3; 0.8–5.16] mmol/l), and less in pound net captures than in trawl captures (T_0, 15.8 [12.5, 18.1; 8.5–20.0] mmol/l, T_{30}, 14.9 [13.1, 17.6; 8.8–20.0] mmol/l) regardless of sample time (Kruskall-Wallis, $P=0.0009$; Dunn's multiple comparison test, $P<0.05$). One turtle became partially entangled in the pound net by one front flipper when the boat entered the net for harvesting fish, but could still surface to breathe. This turtle had the highest initial and 30 min lactate values of the pound net captures (5.1 and 14.7 mmol/l, respectively). Corrected venous bicarbonate concentrations correlated negatively with venous lactate

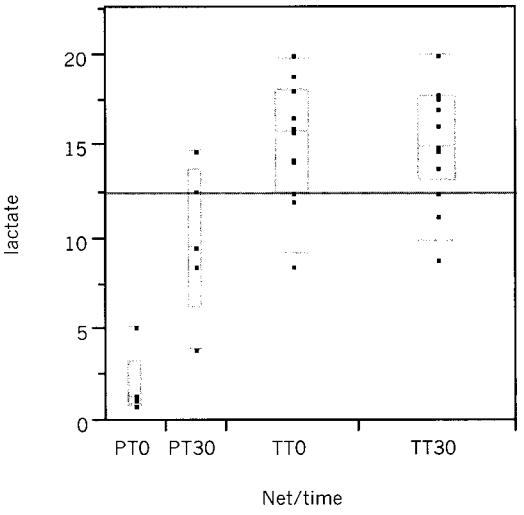

FIGURE 5. Blood lactate (in mmol/l) of loggerhead sea turtles immediately following capture by pound net (PT0, n=5) or trawl (TT0, n=5) and after 30 min on deck (PT30, n=11, and TT30, n=13, for pound net and trawl, respectively). Lactate values were significantly greater in pound net captures at 30 min than initially and less in pound net captures than in trawl captures regardless of sample time.

for both groups including both sample times (Kendall tau b=−0.68, $P<0.0001$, $n=34$). Weight correlated positively with initial venous lactate concentrations for turtles captured by trawl (Kendall tau b=0.62, $P=0.0079$, $n=11$); data were insufficient for evaluating pound net captures.

Intervals from bringing turtles on deck until venipuncture were 6 (3, 8; 2–10) min for trawl captures and 1 (1, 2; 1–2) min for pound net captures. For trawl-captured loggerhead sea turtles initial values varied by time of sampling, in concordance with differences noted between T_0 and T_{30} values, with the exception of pH and PvO_2. Venous pH did not differ according to initial sample time (ANOVA, $R^2=0.046$, $P=0.43$) while values were increased at 30 min. Partial pressure of CO_2 in venous blood values decreased within the 2–10 min span of initial sampling ($R^2=0.47$, $P=0.0034$), as well as at T_{30}. Partial pressure of O_2 in venous blood values increased between 2–10 min ($R^2=0.26$, $P=0.045$), contrary to the decrease at T_{30}. Bicarbonate values decreased ($R^2=0.45$, $P=0.042$), as did values at T_{30}. Lactates did not differ by initial sample time ($R^2=0.12$, $P=0.30$) or at T_{30}.

Because temperature correction of blood gas and pH measurements is a complex and controversial subject, with multiple formulas for performing corrections (Ashwood et al., 1983), comparison of the directly measured 37 C and temperature corrected values is presented in Table 1 for reference. Statistical comparisons between groups were not affected by temperature correction.

DISCUSSION

Trawl-captured loggerheads exhibited a marked acidemia and lactic acidosis when first brought on board. Lactic acidosis failed to resolve to any degree within 30 min, but blood pH did correct to values statistically indistinguishable from those of pound net captures. While $PvCO_2$ of trawl-captured loggerheads did not differ from that of pound net captures, both were elevated compared to resting values for captive-reared Kemp's ridley sea turtles (Stabenau and Hemming, 1993). The resolution of acidemia was accompanied by a decrease in $PvCO_2$ and respiratory rates considerably above reported rates for unrestrained sea turtles (Kraus and Jackson, 1980; Lutcavage and Lutz, 1991). Bicarbonate also decreased slightly. We interpret this as a mixed metabolic (lactic) and respiratory (hypercarbia) acidosis undergoing correction by respiratory alkalosis (hyperventilation) and titration of bicarbonate by lactic acid. The inverse correlation of bicarbonate with lactate concentrations found through both groups and sampling times further suggests titration of bicarbonate by lactic acid. Positive correlation of turtle weight with initial venous lactate concentrations for loggerheads captured by trawl indicates a greater degree

TABLE 1. Directly measured 37 C and temperature corrected median [lower quartile, upper quartile] values for venous pH, $PvCO_2$, and PvO_2 for pound net-captured and trawl-captured loggerhead sea turtles initially (T_0) and 30 min (T_{30}) after capture.

	pH 37 C	pH corrected	$PvCO_2$ 37 C	$PvCO_2$ corrected	PvO_2 37 C	PvO_2 corrected
Pound T_0	7.22 [7.14, 7.28]	7.35 [7.27, 7.40]	90.9 [77.7, 108.3]	61.9 [52.2, 70.5]	72.0 [67.2, 82.8]	64.0 [59.5, 73.2]
Pound T_{30}	7.24 [7.13, 7.26]	7.35 [7.27, 7.38]	62.3 [60.5, 66.2]	42.8 [41.4, 47.4]	75.5 [70.5, 88.8]	66.5 [63.5, 78.5]
Trawl T_0	7.02 [6.97, 7.12]	7.16 [7.08, 7.24]	76.6 [69.0, 97.6]	62.95 [54.7, 85.7]	93.5 [87.0, 104.8]	83.0 [77, 93.2]
Trawl T_{30}	7.13 [7.07, 7.23]	7.25 [7.20, 7.34]	52.2 [47.3, 56.7]	35.2 [32.4, 38.3]	80.0 [75.2, 92.8]	70.5 [67.2, 82]

of anaerobic metabolism during trawl capture in larger turtles. Resolution of lactic acidosis in forcibly submerged sea turtles may require >20 hr (Lutz and Dunbar-Cooper, 1987). Permits mandated prompt release of the turtles following processing, and holding and transportation conditions would have differed considerably between the two capture groups, so turtles in the present study were not held for a 24 hr period to determine if lactic acidosis would resolve.

Elevated PvO_2 was not expected in the trawl-captured loggerheads at the initial sample time. Venous PO_2 is not considered an accurate reflection of PaO_2 though it is lower than PaO_2 (Relman, 1986). Venous PO_2 is a function of PaO_2, cardiac output, and peripheral tissue O_2 extraction. Although arterial and venous blood oxygenation would be expected to decrease in sea turtles subjected to a forced submergence, we did not sample turtles prior to emergence, and they were able to breathe for periods of 2–10 min before venipuncture. During that 2–10 min period there was an increase in PvO_2, which subsided by 30 min. Turtles are capable of reoxygenating rapidly, within a few breaths during brief surface intervals following voluntary dives (Lutcavage and Lutz, 1997), and cardiac output (though not measured) could be expected to have increased during the trawl capture process. Results suggest that peripheral oxygen utilization increased more slowly than oxygen delivery in the immediate period following emergence from a trawl capture but equilibrated by 30 min following capture.

Because pound nets are a comparatively passive capture mechanism, permitting free access to the surface to breathe, it was expected that blood gas and acid/base impacts would be minimal in pound-net-captured loggerheads. However, $PvCO_2$ was markedly elevated compared to resting captive-reared Kemp's ridley sea turtles (Stabenau and Hemming, 1993). Initial lactate values, though lower than those of trawl captures, were still mildly elevated compared to resting Kemp's ridleys in that same study at a median of 1.3 [1.0, 3.3; 0.8–5.16] mmol/l in the current study versus a mean±SE of 0.7±0.1 mmol/l (Stabenau and Hemming, 1993). Furthermore, lactates rose markedly to 9.5 [6.2, 13.6; 4.0–14.8] mmol/l within only 30 min of on-board holding. This compares with mean±SE lactate values of 1.7±0.3 mmol/l in captive-reared Kemp's ridleys subjected to combined land, air and sea transport prior to experimental placement in trawls (Stabenau and Hemming, 1993). Therefore, although some of the increase in lactic acid may be attributable to active escape attempts during on board handling and holding and to being out of the buoyant aqueous environment, most is likely attributable to anaerobic metabolic activity during escape attempts while in the pound net at the time of capture. Indeed, from the time the boat entered the pound net until the turtles were hoisted on board (times not recorded, but typically ranging from 5–10 min), they made continual and mostly submerged attempts of variable intensity to swim through the net. Although lactic acid increased markedly during the 30 min on board following capture from pound nets, venous pH did not shift, indicating that compensatory mechanisms were able to keep pace during the time period monitored. A wide range of vertebrate species tightly regulate normal blood pH within about 0.2 pH units (Schmidt-Nielsen, 1990). The complete range of corrected $PvCO_2$ values for loggerheads captured in pound nets was 7.25–7.45, conforming to 0.2 pH units, and may be taken as a representative physiologic range for loggerheads at 27.1–29.2 C. Corrected $PvCO_2$ values less than 7.16, median for the trawl-captured loggerheads, represents a severe acidemia. This could compromise turtle viability, particularly if the turtle was subjected to a subsequent trawl prior to complete recovery (Lutcavage and Lutz, 1997). Respiratory compensation, not an option during trawl captures, appears to be

critical in maintaining physiologic blood pH.

Although values for base excess and oxygen saturation are included in the CG4+ cartridge panel, they were not included in this study. Base excess is calculated by the iStat with a modification of the Van Slyke equation, which requires assumptions regarding normal hemoglobin and plasma protein concentrations for humans (Siggaard-Anderson, 1974) that hold questionable relevance for debilitated humans, let alone reptiles of any condition. Oxygen saturation calculations rely on species-specific differences in blood oxygen affinity, which differs markedly between sea turtles and humans, between sea turtle species (Lapennas and Lutz, 1982), and between juveniles and adults of the same sea turtle species (Wood et al., 1984).

In summary, though methodology differs between this and prior studies, well-conditioned wild sea turtles subjected to actual trawl captures in the field were impacted in blood gas and acid/base effects similarly to captive sea turtles subjected to forced submergence in laboratory settings. Trawl capture caused greater perturbations in blood gas, acid-base, and lactate status than did pound net capture, even with trawl time limited to 30 min. Capture in a relatively passive system (pound net) may also have non-trivial effects on the respiratory physiology of wild loggerheads, however, which is well to bear in mind during any capture procedure. The potential impact of multiple captures in fisheries activities on a sea turtle that has not sufficiently recovered from a previous capture event has been commented upon previously (Lutcavage and Lutz, 1997).

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LITERATURE CITED

ASHWOOD, E. R., G. KOST, AND M. KENNEY. 1983. Temperature correction of blood-gas and pH measurements. Clinical Chemistry 29: 1877–1885.

BERKSON, H. 1966. Physiological adjustments to prolonged diving in the Pacific green turtle (*Chelonia mydas agassizii*). Comparative Biochemistry and Physiology 18: 101.

———. 1967. Physiological adjustments to deep diving in the Pacific green turtle (*Chelonia mydas agassizii*). Comparative Biochemistry and Physiology 21: 507.

BUTLER, P. J., W. K. MILSOM, AND A. J. WOAKES. 1984. Respiratory, cardiovascular and metabolic adjustments during steady state swimming in the green turtle, *Chelonia mydas.* Journal of Comparative Physiology B 154: 167–174.

CHITTICK, E. J., M. A. STAMPER, J. BEASLEY, G. A. LEWBART, AND W. A. HORNE. 2002. Medetomidine-ketamine-sevoflurane anesthesia for injured loggerhead sea turtles. Journal of the American Veterinary Medical Association 221: 1019–1025.

EPPERLY, S. P. 2003. Fisheries-related mortality and turtle excluder devices (TEDs). *In* The biology of sea turtles II. P. L. Lutz, J. A. Musick and J. Wyneken (eds.). CRC Press, Boca Raton, Florida, pp. 339–353.

———, J. BRAUN, AND A. VEISHLOW. 1995. Sea turtles in North Carolina waters. Conservation Biology 9: 384–394.

———, AND W. G. TEAS. 2002. Turtle excluder devices—Are the escape openings large enough? Fishery Bulletin 100: 466–474.

HENWOOD, T. A., AND W. E. STUNTZ. 1987. Analysis of sea turtle captures and mortalities during commercial shrimp trawling. Fishery Bulletin 85: 813.

HOCHACHKA, P. W., T. G. OWEN, J. F. ALLEN, AND G. C. WHITTOW. 1975. Multiple end products of anaerobiosis in diving vertebrates. Comparative Biochemistry and Physiology 50B: 17.

HOLLANDER, M., AND D. A. WOLFE. 1973. Nonparametric statistical methods. John Wiley & Sons, New York, New York, 503 pp.

KRAUS, D. R., AND D. C. JACKSON. 1980. Temperature effects on ventilation and acid-base balance of the green turtle. American Journal of Physiology 239: 254–258.

LAPENNAS, G. N., AND P. L. LUTZ. 1982. Oxygen affinity of sea turtle blood. Respiratory Physiology 48: 59–74.

LUTCAVAGE, M. E., AND P. L. LUTZ. 1991. Voluntary diving metabolism and ventilation in the logger-

head sea turtle. Journal of Experimental Marine Biology and Ecology 147: 287.

———, AND ———. 1997. Diving physiology. *In* The biology of sea turtles. P. L. Lutz and J. A. Musick (eds.). CRC Press, Boca Raton, Florida, pp. 277–296.

LUTZ, P. L., AND T. B. BENTLEY. 1985. Respiratory physiology of diving in the sea turtle. Copeia 1985: 671–697.

———, AND A. DUNBAR-COOPER. 1987. Variations in the blood chemistry of the loggerhead sea turtle, *Caretta caretta.* Fishery Bulletin 85: 37–43.

RELMAN, A. S. 1986. Blood gases: Arterial or venous? New England Journal of Medicine 315: 188–189.

MAGNUSON, J. J., K. A. BJORNDAL, W. D. DUPAUL, G. L. GRAHAM, D. W. OWENS, C. H. PETERSON, P. C. H. PRITCHARD, J. I. RICHARDSON, G. E. SAUL, AND C. W. WEST. 1990. Decline of the sea turtles: Causes and prevention. National Academy Press, Washington, D.C., 259 pp.

ORAVETZ, C. A. 1999. Reducing incidental catch in fisheries. *In* Research and management techniques for the conservation of sea turtles. K. L. Eckert, K. A. Bjorndal, F. A. Abreu-Grobois and M. Donnely (eds.). IUCN/SSC Marine Turtle Specialist Group Publication No. 4, pp. 189–193.

SCHMIDT-NIELSEN, K. 1990. Animal physiology: Adaptation and environment, 4th Edition, Cambridge University Press, Cambridge, UK, pp. 87–88.

SEGARS, A., D. WHITAKER, B. STENDER, M. ARENDT, AND S. MURPHY. 2001. Analyses of blood chemistry in trawl-caught *Caretta caretta* and *Lepidochelys kempi* from southeastern United States. Proceedings of the International Association of Aquatic Animal Medicine 32: 83.

SIGGAARD-ANDERSEN, O. 1974. The acid-base status of the blood, 4th Edition, Williams & Wilkins, Baltimore, Maryland, 229 pp.

STABENAU, E. K., AND T. A. HEMING. 1993. Determination of the constants of the Henderson-Hasselbalch equation, aCO2 and pKa, in sea turtle plasma. Journal of Experimental Biology 180: 311–314.

———, ———, AND J. F. MITCHELL. 1991. Respiratory, acid-base and ionic status of Kemp's ridley sea turtles (*Lepidochelys kempi*) subjected to trawling. Comparative Biochemistry and Physiology 99A: 107–111.

WOOD, S. J., R. N. GATZ, AND M. L. GLASS. 1984. Oxygen transport in the green sea turtle. Journal of Comparative Physiology 154: 275–280.

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