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A comparison of American lobster size structure and abundance using standard and ventless traps

Abigail S. Clark[a,*], Steven H. Jury[b], Jason S. Goldstein[c,d], Thomas G. Langley[c], Winsor H. Watson III[c]

[a] Department of Fisheries and Aquatic Sciences, University of Florida, Gainesville, FL, USA
[b] University of New England, Biddeford, ME, USA
[c] Department of Biological Sciences and School of Marine Sciences and Ocean Engineering, University of New Hampshire, Durham, NH, USA
[d] Department of Biology, Eastern Connecticut State University, Willimantic, CT, USA

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ABSTRACT

Ventless (escape vents blocked) trap surveys are becoming increasingly common and provide data that are useful for making well-informed management decisions. The purpose of this study was to conduct ventless and standard trap surveys, in parallel with SCUBA surveys, to determine how lobster catch in both types of traps relates to the size structure and abundance of lobster populations on the bottom. Because trap saturation may affect catch-per-unit-effort, we also quantified how catch changed over time by pulling traps after a period of 10 distinct soak times, ranging from 2 to 96 h. All surveys were carried out in 2010 and 2011, at a study site along the coast of New Hampshire, USA. Ventless traps collectively captured ~10 times as many lobsters as standard traps, but the mean size of the lobsters captured did not differ between the trap types. Catch in standard traps changed little over time and thus the time to saturate was difficult to assess. However, ventless traps saturated between 16 and 24 h. Ventless traps saturated at all lobster densities, but had higher final catch values at times when lobsters were most abundant (as determined by SCUBA surveys). These data indicate that ventless traps provide valuable information about natural lobster populations, which can be useful in the assessment of this valuable fishery.

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1. Introduction

Managing the American lobster, *Homarus americanus* (Milne-Edwards, 1837), fishery and mitigating some of the potential impacts of overfishing are important to ensuring that the fishery remains sustainable. The fishery presently accounts for 69% of all landings in the state of Maine (ex-vessel, in terms of value) and is considered a vital marine resource in many Atlantic coastal communities (DMR, 2013). Therefore, state and federal governments have established programs to help reduce overexploitation of lobsters. For example, the Interstate Fishery Management Plan (FMP) for American Lobsters and the Atlantic Coastal Fisheries Cooperative Management Act have implemented regulations such as: (1) prohibiting the harvesting of lobsters with eggs; (2) size limits (minimum: 3 1/4 in., or 83 mm; maximum: 5 in., or 127 mm in the Gulf of Maine fishery) and; (3) V-notching (marking the telson of egg-bearing females in an effort to protect them from future harvesting) (DMR, 2009; NOAA, 2012; ASMFC, 2015a). Supplemental sampling programs (e.g., sea-sampling) have also been established by many state agencies to obtain data that will improve their ability to track the health of the fishery.

Regional and local fishery-independent and fishery-dependent sampling programs are used by managers to assess lobster abundance and spatial distribution (ASMFC, 2015b). At the Federal level, beginning in the 1960s, NOAA Fisheries Service has conducted fishery-independent trawl surveys to determine the abundance and distribution of lobster populations. However, this sampling method is generally restricted to depths greater than 50 m on 'trawlable bottom' and is, therefore, not always practical for stock assessment of lobsters residing in shallower, inshore waters (Chen et al., 2006). While inshore trawl surveys also provide useful information, they are challenging to implement due to gear conflicts with existing commercial lobster traps (NH Fish and Game, 2012). Information regarding inshore stocks is therefore primarily derived from fishery-dependent sampling data, such as those collected via port and sea sampling efforts (DMR, 2001; Scheirer et al., 2004).

* Corresponding author. Tel.: +1 6032199502.
E-mail address: clarkab@epi.ufl.edu (A.S. Clark).

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Lobstermen, however, commonly fish traps in areas where the densities of legal-sized lobsters are expected to be relatively high and, consequently, the catch from these locations may overestimate the abundance of larger (i.e., legal-sized), inshore lobsters. Moreover, standard lobster traps are size-selective, so small lobsters are often under-represented in the catch. To supplement these and other sampling techniques, the Maine Department of Marine Resources (DMR) and Massachusetts Division of Marine Fisheries (MADMF) have instituted ventless trap surveys in an effort to more accurately assess the size structure and abundance of lobsters in a given area (Scheirer et al., 2004; MADMF, 2009; DMR, 2011).

In a previous study assessing lobster-trap interactions, Jury et al. (2001) found that only 6% of the lobsters entering standard traps are captured. Of the remaining 94%, 28% exited through the escape vent and 72% through the kitchen entrance. Standard trap catch-per-unit-effort (CPUE) data, therefore, only weakly correlate ($r^2 = 0.471$) with the abundance of lobsters on the bottom (Watson and Jury, 2013). Ventlesss traps and commercial standard traps are similar in design, however ventless traps do not have escape vents that allow small, sublegal lobsters to leave the parlor (Estrella and Glenn, 2006).

While ventless trap surveys are widely used as experimental units for fishery-independent trap surveys across coastal New England States, very few studies have actually analyzed the dynamics of ventless traps and the relationship between ventless trap catch and lobster abundance. Courchene and Stokesbury (2011) performed a study comparing ventless trap catch to the size frequency distribution and abundance of a lobster population in Massachusetts, USA. Ventless and standard traps that were fished for 72–120 h captured relatively larger lobsters, with a more male skewed sex ratio, than observed in SCUBA surveys. This study also provided insight into the effect that habitat and temperature may have on ventless trap catch. Ventless trap CPUE increased with substrate complexity and decreased when temperatures increased above 12 °C. In addition, trap saturation may have caused a reduction in trap catch, but as the authors suggest, future studies are required to confirm this.

One of the factors that may lead to discrepancies between the actual lobster abundance and catch in traps is “trap saturation”, or the ability of existing catch to reduce future catch (Miller, 1990), which leads to a plateau in total catch over time. Trap saturation has been investigated in a variety of crustacean fisheries, but much remains unknown about the causes of this phenomenon (Miller, 1979; Barber and Cobb, 2009). One possible explanation for reduced catch is the behavioral interactions among species congregating in, or around, traps (Addison and Bannister, 1998; Jury et al., 2001). For example, pre-stocking traps, by tethering lobsters inside of them, reduces catch in traps fished for 24 h (Richards et al., 1983; Addison, 1995). In a study conducted by Barber and Cobb (2009), Dungeness crab (*Cancer magister*) territoriality and aggression discouraged other crabs from entering the pot. Similar behaviors have been observed in other studies, where large lobsters tended to prevent smaller lobsters from trying to enter traps, thus limiting the number of entries (Jury et al., 2001; Watson and Jury, 2013). Saturation leading to decreased entry rates has also been observed in fish pots used to catch Atlantic cod (*Gadus morhua*; Ovegård et al., 2011), sablefish (*Anoplopoma fimbria*; High and Beardsley, 1970) and squirrelfish (*Holocentrus adscensionis*; Stoner, 2004). Thus, it is likely that behavior plays a significant role in modulating trap dynamics, leading to alterations in the final amount and size structure of the catch.

The primary goal of this study was to determine if catch in ventless traps provides a better index of the size structure and abundance of lobsters on the bottom than catch in standard traps. A secondary goal was to determine if ventless traps saturated and, if so, whether this limited their ability to catch lobsters in proportion to the density of lobsters on the bottom. In order to accomplish these goals, standard and ventless traps were fished in pairs off the coast of New Hampshire, USA for soak times ranging from 2 to 96 h. At the conclusion of each soak period, the number of lobsters captured and their size frequency distribution were compared to the same data obtained using dive surveys.

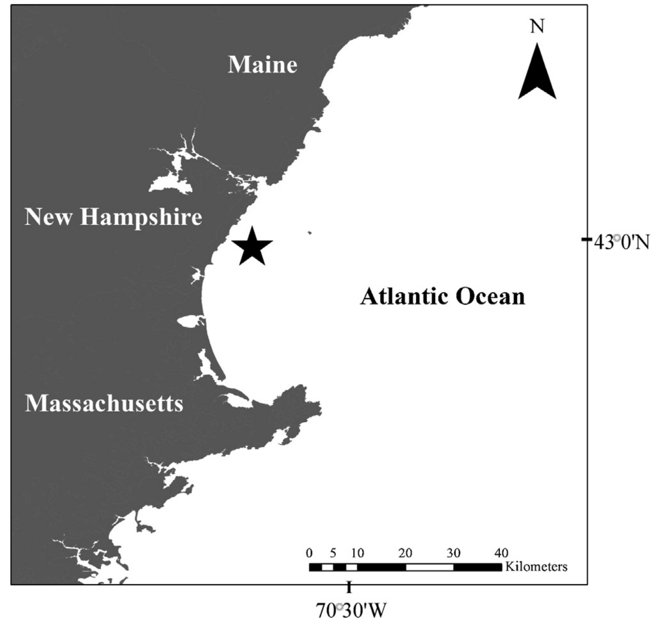

Fig. 1. Map of study site, off the coast of Wallis Sands State Beach in Rye, NH, USA. The star represents location of the ventless-standard trap pairs.

2. Materials and methods

2.1. Study site

All data were collected in waters ranging from 7 to 10 m deep, from May (or June) through October of 2010 and 2011, off of coastal New Hampshire, NH, USA (Fig. 1). The study area was 90,000 m^2, with a primarily sand bottom, which made it ideal for visualizing lobsters during SCUBA surveys, as well as providing a relatively homogenous landscape for conducting the trap trials. This area is also typically devoid of active lobstermen, and it was the site for previous investigations using standard traps (Jury et al., 2001; Watson and Jury, 2013).

Another valuable feature of this site is that the density of lobsters changes on a seasonal basis (Watson and Jury, 2013). Much of this variation in lobster density is probably related to seasonal shifts in water temperature, since lobsters tend to behaviorally thermoregulate, preferring areas with water temperatures of ~16 °C (Crossin et al., 1998; Jury and Watson, 2013). These seasonal fluctuations in lobster density made it possible to determine how CPUE and trap saturation in both types of traps varied with the abundance of lobsters on the bottom, as determined via SCUBA surveys (see below).

Bottom temperature at the study site was monitored using HOBO data loggers (Onset Computer Corp, Onset, MA) that were programmed to record the temperature every 30 min throughout the study period. The temperature loggers were attached to haphazardly selected traps fished at the study site. Temperature data for some dates (i.e., 9/2–9/8/10 and 9/22–10/3/10) were not obtained, due to storms, so temperature data collected 6 km away, at the University of New Hampshire Coastal Marine Laboratory, were substituted for these time periods.

2.2. SCUBA surveys

A total of 20 dive surveys were conducted in 2010 and 2011 ($n = 8$ and 12, respectively). Dive surveys were carried out a week before and/or after fishing traps at the same location. Two different types of surveys were performed during the field season: (1) surveys to collect lobsters for determining density as well as lobster sexes and sizes, and (2) surveys just to quantify the density of lobsters. To assess the abundance and size frequency composition of lobsters on the bottom, divers collected lobsters present along transects that were 30–60 m long and 4–6 m wide, depending on visibility. Two SCUBA divers, one on each side of the transect line, swam a total of four transects per survey. All lobsters were then brought to the surface where the carapace length (CL) of each lobster was measured using calipers and their sex was determined. Lobsters were then released at the site of capture within 20 min of being collected. To measure lobster abundance, two SCUBA divers swam four transects similar to those previously described. Instead of collecting lobsters, however, lobsters were only counted. In general, abundance surveys were conducted within a week prior to fishing traps to avoid handling lobsters and potentially causing them to disperse from the study area, while the other surveys were carried out after traps were fished.

2.3. Traps

A total of 21 pairs of ventless and standard traps (standard designs provided by MA Department of Marine Fisheries), were deployed a total of 372 times by a single vessel at the study site, beginning in May or June of each year. Traps were of the same configuration used in ongoing state surveys throughout the region with 17 m of line connecting each standard and ventless trap. Traps were deployed parallel to shore, and the trap pairs were set 50–100 m apart from each other. Every trap pair was labeled and returned to the same location for the duration of the study. For each trial, traps were hauled in a haphazard sequence.

Standard traps were similar in design to the single parlor traps used in the fishery, but they were made with 2.54 cm × 2.54 cm wire mesh, rather than the 3.81 cm × 3.81 cm mesh that is used for commercial traps. Each rectangular trap used in this study was 90 cm × 47 cm × 35 cm and had two main compartments, a kitchen and parlor (see Jury et al., 2001 for an illustration). The kitchen, which contained the bait and 12.7-cm entrance heads, was connected to the parlor via a mesh funnel that allowed lobsters to move from the kitchen to parlor. Single escape vents (14.6 cm × 4.9 cm) were used to allow sublegal-sized lobsters (CL < 83 mm) to exit the trap (Estrella and Glenn, 2006). Unlike standard traps, ventless traps lacked escape vents. Trap bait, purchased from the Little Bay Lobster Co. (Newington, NH, USA), consisted of three (~200 g) frozen herring (*Clupea harengus*).

2.4. Experimental protocol

Approximately every two weeks, groups of three randomly selected trap pairs were baited and fished for the following soak times: 2, 4, 8 (or 6), 16 (or 10), 24, 48, 72, and 96 h. This protocol yielded $n = 3$ deployments for each trap type, for each time period, and for each trial. These three trap pairs (trap = experimental unit) were treated as replicates. A total of 12 saturation trials were completed between 2010 and 2011 (Table 1), and these trials were then matched with SCUBA surveys that were conducted during the same time period.

2.5. Data analyses

The overall objective of this study was to determine the relationship between catch in each type of trap (CPUE) and lobster abundance (density/m^2). Transforming the mean CPUE data (natural log) prior to analysis satisfied normality assumptions. A Student's *t*-test was then used to compare the log-transformed CPUE data of standard traps to those of ventless traps. All variations in this paper are reported as standard error of the mean (SEM) and all averages reported are given ± SEM· All statistical analyses were performed using Instat software (GraphPad Software, Inc., La Jolla, California, USA).

Ventless trap CPUE data were also used to plot saturation curves. After plotting CPUE vs. soak time, logarithmic regression analyses were performed to determine the relationship between ventless trap CPUE and the estimated lobster abundance. Similar analyses were completed for ventless trap CPUE collected at different lobster densities to determine if lower densities yielded a stronger logarithmic fit with CPUE than higher densities. Segmented linear regression analyses were then used to detect the point at which lobster entry rate in ventless traps decreased as soak time increased. Linear regression analyses were used to determine which of the soak times produced the best correlation between ventless trap CPUE and lobster density

3. Results

3.1. Seasonal fluctuations in water temperature and lobster density

Water temperature at the study site fluctuated seasonally, ranging from daily averages of 8.62 ± 0.05 °C in June to 18.64 ± 0.38 °C in September of 2010 and from 7.16 ± 0.04 °C in June to 19.66 ± 0.64 °C in August of 2011 (Fig. 2A). The density of lobsters at the study site, as determined by SCUBA surveys, ranged from 0.001 lobsters/m^2 to a peak of 0.16 ± 0.004 lobsters/m^2 (Fig. 2B). The means for 2010 and 2011 were 0.051 ± 0.012 lobsters/m^2 and 0.053 ± 0.008 lobsters/m^2, respectively. In general, lobster densities were highest when water temperatures were the warmest.

3.2. The influence of gear selectivity on the size composition of catch

A total of 7374 lobsters were collected by traps and by divers between 2010 and 2011. Of these lobsters, 568 (7.70%) were captured using standard traps and 6543 (88.7%) using ventless traps. The remaining 263 lobsters (3.57%) were collected during SCUBA surveys. The size (mm CL) of lobsters captured in standard traps (mean size: 61.98 ± 0.61 mm) was not significantly different from the size of lobsters caught in ventless traps (Fig. 3; 62.38 ± 0.12 mm; $P = 0.82$, unpaired t-test). The mean size of lobsters on the bottom (48.06 ± 0.90 mm), collected by SCUBA divers, was smaller and significantly different from the mean size of lobsters captured in either type of trap ($P < 0.0001$, unpaired t-test). Traps tended to capture many more lobsters in the 60 to 80 mm CL size range than were observed on the bottom.

3.3. Comparison of catch in ventless vs. standard traps

While the average size of lobsters caught in standard and ventless traps was similar, significantly more lobsters were caught in ventless traps compared to standard traps (Fig. 4A; $P < 0.0001$, unpaired t-test). Of the lobsters captured in traps fishing for 24 h, 93.78% were from ventless traps and only 6.22% were from standard traps. When lobster density was relatively low (i.e., June), this difference was not as pronounced as during periods of higher lobster

Table 1
Summary of standard vs. ventless trap trials. Trials took place from May or June through October in both years. Lobster density is presented in lobsters/m^2 (±SEM).

2010 Trial no.	Start date	End date	Lobster density	No. of trap pairs fished
1	6/4/10	6/28/10	0.03 ± 0.005	29
2	7/6/10	7/9/10	0.033 ± 0.008	24
3	8/2/10	8/22/10	0.056	30
4	8/30/10	9/27/10	0.16 ± 0.004	22
5	10/8/10	10/20/10	0.001	22
2011 Trial no.				
1	5/31/11	6/13/11	0.024 ± 0.007	24
2	6/17/11	6/27/11	0.094	24
3	6/28/11	7/12/11	0.053 ± 0.009	32
4	7/19/11	7/29/11	0.01	34
5	8/5/11	8/26/11	0.11 ± 0.028	37
6	8/30/11	9/23/11	0.068 ± 0.015	40
7	9/23/11	10/31/11	0.011 ± 0.007	54

density. For example, the average ventless trap CPUE in August was 26 ± 2.46 after 24 h while the average standard trap CPUE was only 1.23 ± 0.46. In contrast, ventless trap CPUE in June was 16.15 ± 2.1 while standard traps captured 1.43 ± 0.22 lobsters after a 24-h soak period. A similar trend was observed after fishing traps for 48 h (Fig. 4B), with ventless traps capturing significantly more lobsters than standard traps, particularly during periods of high density ($P < 0.0001$, unpaired t-test). Considering all 24- and 48-h catch, the geometric mean for ventless trap CPUE was approximately 10 times the CPUE for standard traps (17.59 vs. 1.63).

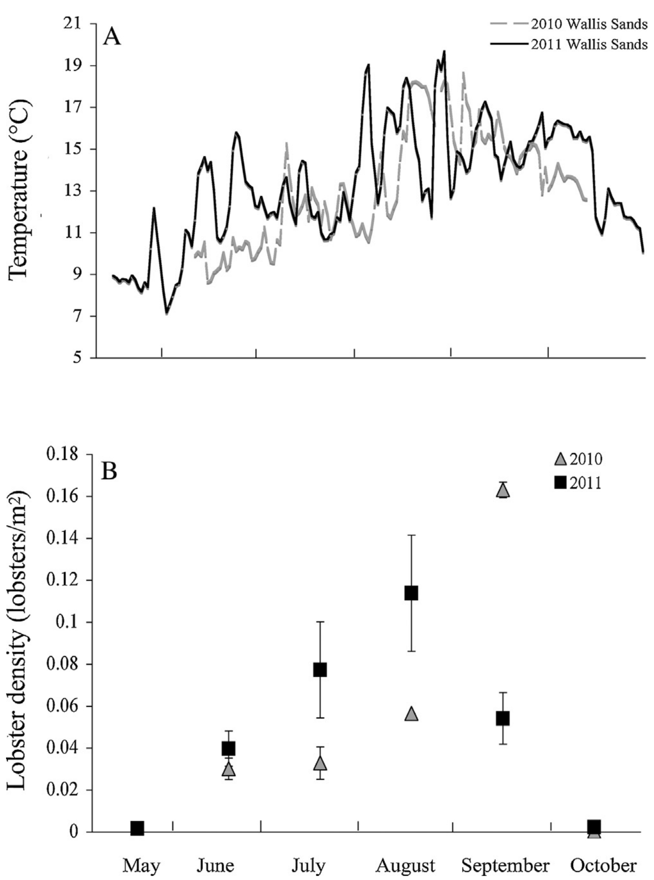

Fig. 2. Seasonal fluctuations in (A) temperature and (B) lobster density (lobsters/m^2) at the study site. Temperature (A) was recorded every 30 min and averaged for each day, while lobster abundance (B) was determined biweekly by SCUBA surveys. Both temperature and lobster density data were collected between May (or June) and October of 2010 and 2011.

3.4. Trap saturation

Standard and ventless traps were fished for soak times ranging from 2 to 72 h. In general, ventless trap CPUE increased steadily for the first 16–24 h and then reached a plateau (Fig. 5; $P = 0.0025$, one-way ANOVA), while standard trap CPUE changed little over this same time period ($P = 0.4465$, one-way ANOVA). Regression analysis of mean catch values ($n = 3$) showed no relationship between

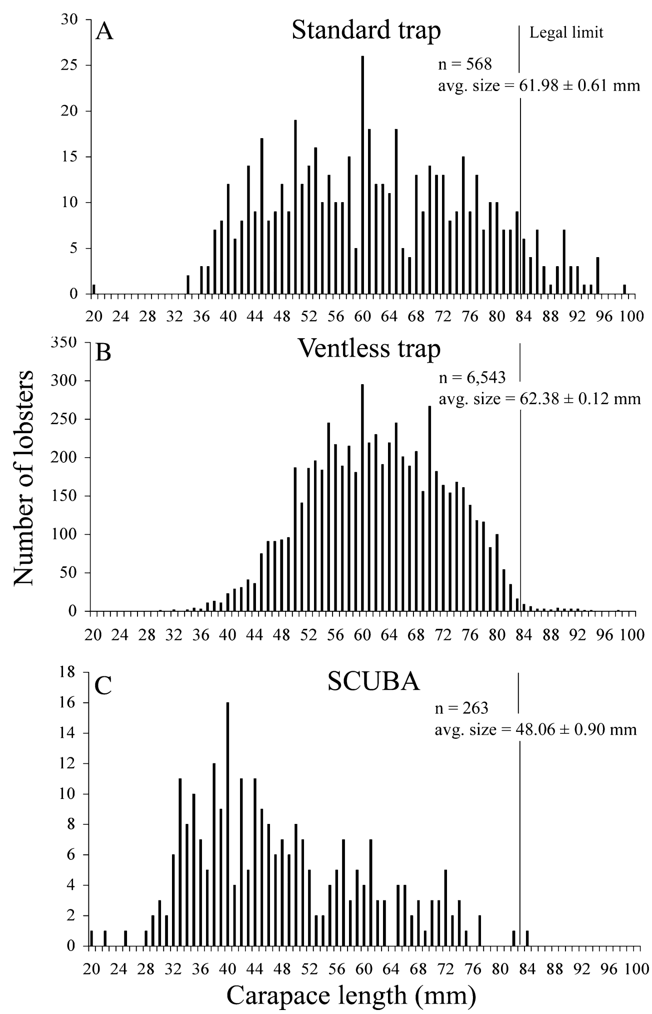

Fig. 3. The size frequency distribution of lobsters captured in standard traps (A), ventless traps (B), and during SCUBA surveys (C), between May (or June) and October of 2010 and 2011. The vertical line indicates the minimum legal limit for lobsters in New Hampshire, USA. Note the *Y*-axis is different for each graph.

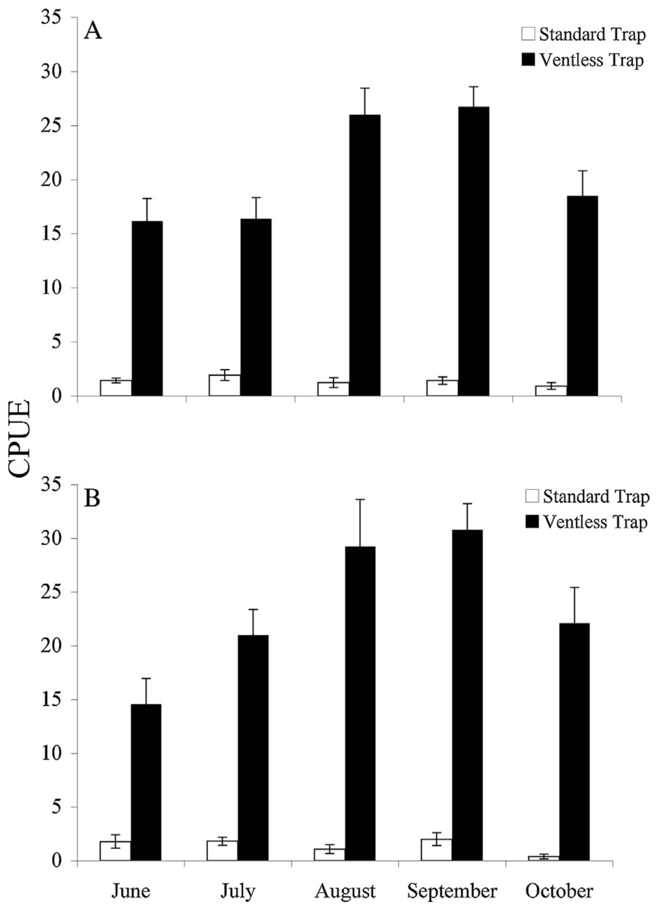

Fig. 4. CPUE in standard traps and ventless traps after (A) 24 h and (B) 48 h, based on data collected from June through October 2010. There was a significant difference between standard trap CPUE and ventless trap CPUE after 24 h (A; $n = 19$) and after 48 h (B; $n = 18$) for each month ($P < 0.0001$, unpaired t-test). *Y* error bars indicate ± SEM of all catch collected after 24 and 48 h.

standard trap catch and soak time, yet revealed a significant logarithmic increase in ventless trap catch as soak time increased ($r^2 = 0.0045$ and $r^2 = 0.9523$ for standard and ventless traps, respectively).

Even though there was no significant difference between catch at any time period for standard traps in 2010 (Fig. 6A; $P = 0.7485$, one-way ANOVA) and 2011 (Fig. 6B; $P = 0.6847$, one-way ANOVA), there were differences at certain time points for ventless traps ($P < 0.0001$ for both 2010 and 2011, one-way ANOVA). Specifically, ventless traps appeared to saturate 16 h (Fig. 6A; $P = 0.4611$,

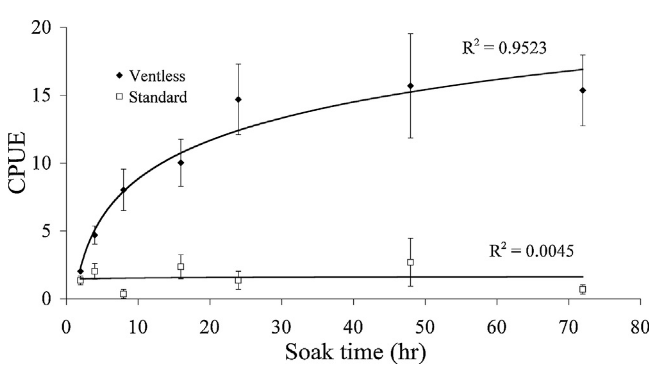

Fig. 5. Typical mean catch data obtained from standard ($n = 3$) and ventless ($n = 3$) traps sampled at each soak time during one saturation trial, in June 2011.

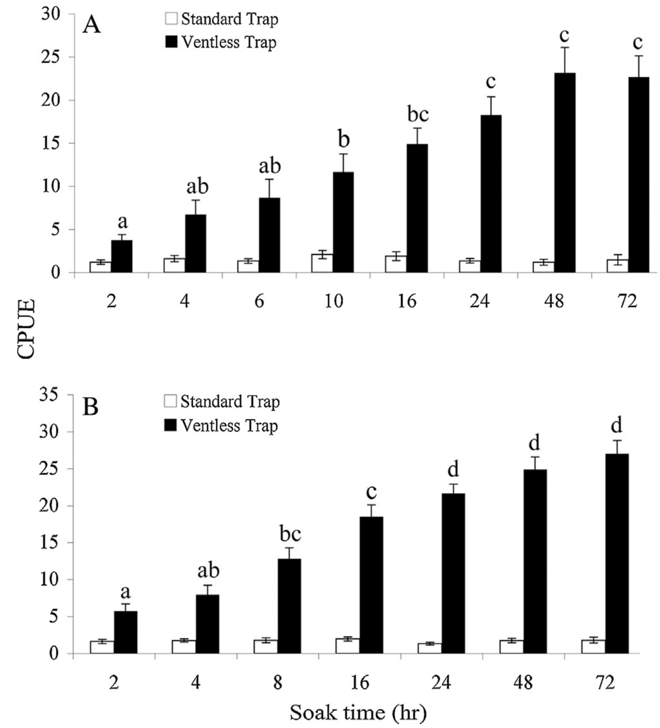

Fig. 6. Comparison of the mean catch in ventless and standard traps during all saturation trials conducted in (A) 2010 and (B) 2011. There was a significant difference between catch in trap types after most individual soak times ($P < 0.0001$, one-way ANOVA) in 2010 ($n = 13$–23 trap pairs/soak time) and 2011 ($n = 17$–53 trap pairs/soak time). Differences between catch in ventless traps across soak times are indicated by letters above the bars. Note that all one-way ANOVAs were followed by Tukey's Multiple Comparison Tests.

one-way ANOVA) and 24 h (Fig. 6B; $P = 0.0804$, one-way ANOVA) after deployment.

While ventless traps appeared to saturate between 16 and 24 h (Fig. 6A and B) under the conditions tested, catch at all time points tended to be greater at higher lobster densities relative to lower lobster densities (Fig. 7A). For example, the geometric mean of CPUE after 24 h was 14.2 and 28.5 for low and high lobster densities, respectively. At both low and high densities, there were strong relationships between average catch and soak time ($r^2 = 0.9401$ and $r^2 = 0.9661$ for ventless trap CPUE collected during high lobster densities, $n = 3$, and low lobster densities, $n = 5$, respectively). Using segmented linear regression analyses, saturation curves were examined at low and high densities to determine at which time points traps began to saturate. Catch rate at low densities declined from 0.8 lobsters/h during the first 17 h of soak time to 0.09 lobsters/h at subsequent time points. Similarly, at high densities, catch rate was initially 1.0 lobsters/h, but then declined to 0.03 lobsters/h after 20.92 h (Fig. 7B). Therefore, regardless of the density of lobsters on the bottom, there was a clear reduction in catch rate after ∼16–24 h.

The relationship between ventless trap catch and lobster density was examined for each of the time intervals that were studied in both 2010 and 2011 (2, 4, 16, 24, 48, and 72 h). The strongest overall relationship between CPUE and lobster density was obtained after soak times of 16, 24 and 48 h (16 h: $r^2 = 0.4067$, 24 h: $r^2 = 0.4355$, 48 h: $r^2 = 0.6576$, Fig. 8A). Linear regression analyses were only performed on standard trap CPUE collected after 16, 24 and 48 h, since ventless trap catch at these same soak times exhibited the strongest relationship with lobster density. In general, there was a weaker relationship between standard trap catch and lobster density compared to that of ventless traps (16 h: $r^2 = 0.1429$, 24 h: $r^2 = 0.07517$, 48 h: $r^2 = 0.01646$, Fig. 8B).

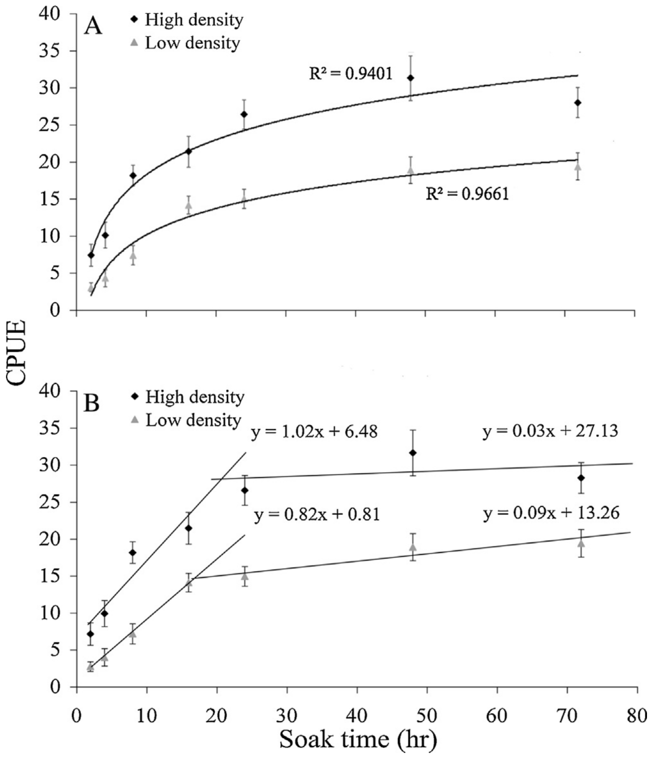

Fig. 7. Average CPUE after different soak times, in ventless traps, at two densities (7A): low (0 to 0.04 lobsters/m^2; n = 5 trials) and high (1 to 1.5 lobsters/m^2; n = 3 trials). Logarithmic regression analyses yielded coefficients of determination between 0.9401 and 0.9661. Importantly, note that the final catch was greater at the higher densities. At a high density of 0.114 ± 0.028 lobsters/m^2 (7B), rate of catch was 1.02 lobsters/h before leveling off after approximately 20.92 h. Catch rate at the low density (0.024 ± 0.007 lobsters/m^2), unlike that of the high density, slowed down after 17.11 h.

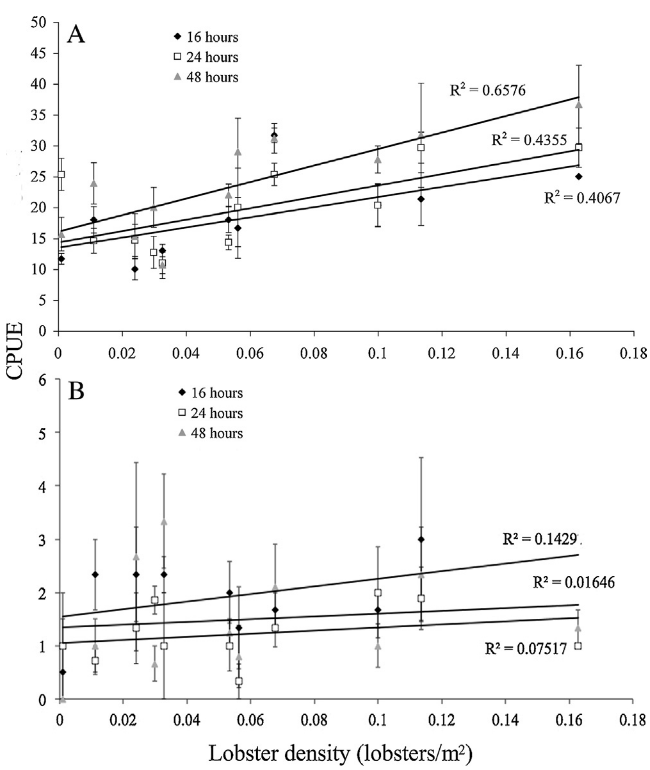

Fig. 8. The relationship between CPUE and lobster densities, for soaks of 16, 24, and 48 h, for (A) ventless traps and (B) standard traps. Each point represents mean catch data (n = 3–7 traps/soak time) collected during 2010 and 2011.

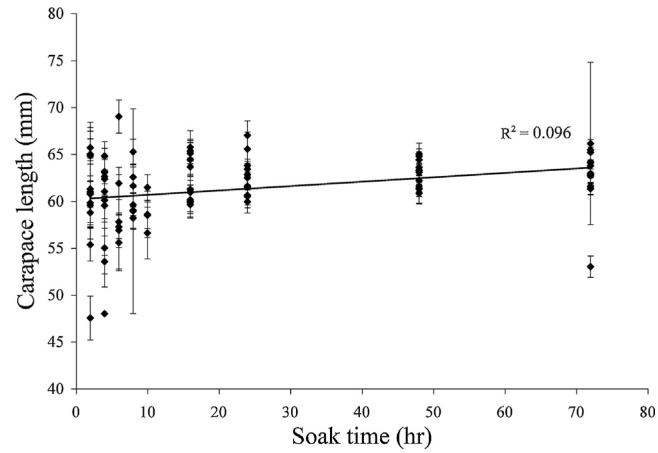

Fig. 9. Mean sizes (±SEM) of lobsters collected in ventless traps (n = 3–7 traps/point) at each soak time. Sizes of all catch collected throughout the 12 trials are presented here (n = 5 from 2010 and n = 7 from 2011).

3.5. Size frequency composition of catch across soak times

Based on data from all 12 trials, there was no strong relationship between the size of all lobsters captured in ventless traps and increasing soak time (Fig. 9; r^2 = 0.096; P = 0.065, one-way ANOVA). This relationship was also examined by categorizing lobsters into three size classes, as done by Watson and Jury (2013; <65 mm, 65–83 mm, and >83 mm) and then comparing the mean CPUE for each size class, at each soak time (Fig. 10). In general, while the

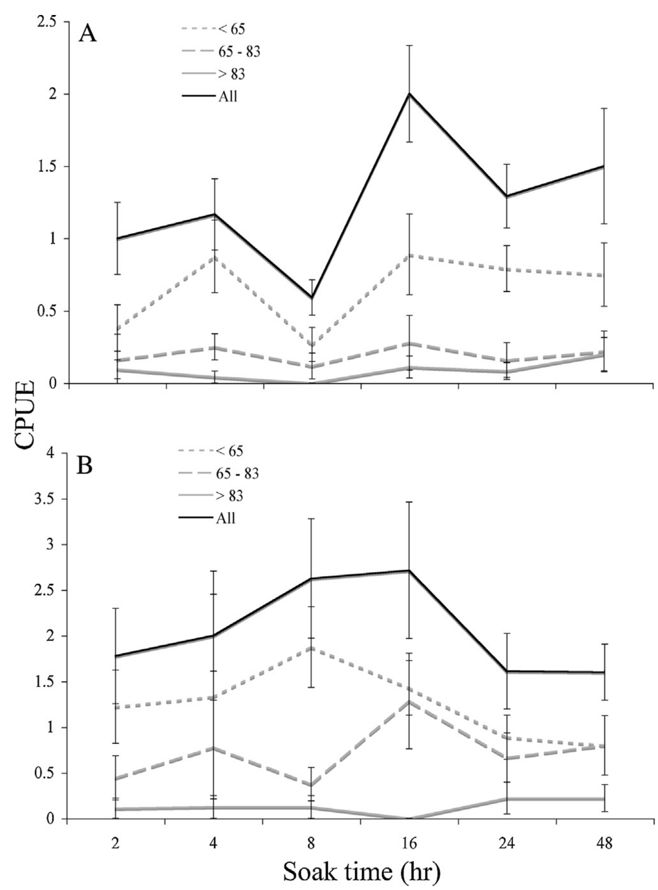

Fig. 10. CPUE of different size classes of lobsters (<65 mm, 65–83 mm, and >83 mm), after different soak times, in ventless traps at low lobster densities (A; n = 5 trials) and high lobster densities (B; n = 3 trials).

catch of smaller lobsters was always higher than larger ones, there was no clear trend over time for any of the size classes examined, either at low or high lobster densities.

4. Discussion

It is now generally accepted that standard lobster traps are selective, making it problematic to use these traps to determine both the size structure and density of lobsters in a given area. As a result, various agencies have turned to ventless traps as a standardized method to more accurately assess lobster populations. A major goal of this study was to determine if the catch in ventless traps more accurately represents the size structure and density of lobsters on the bottom as compared to catch in standard traps. As expected, we found that ventless traps typically captured up to 10 times more lobsters than standard traps, but, somewhat surprisingly, the mean size of the lobsters captured in ventless traps was not significantly different than those retained by standard traps. Finally, while standard traps never saturated under the conditions tested, ventless traps consistently saturated between 16 and 24 h, at all densities tested. Thus, ventless traps appear to have some advantages, from a fishery assessment perspective, over standard traps.

4.1. Lobster movement and density

It is well known that American lobsters undergo seasonal movements between inshore and offshore waters throughout their range (reviewed in Krouse, 1980; Haakonsen and Anoruo, 1994; Lawton and Lavalli, 1995). Cues that may cause lobsters to migrate include changes in salinity (Jury et al., 1994a,b, 1995; Watson et al., 1999), water temperatures (Cooper and Uzmann, 1971; Pezzack and Duggan, 1986; Karnofsky et al., 1989; Jury et al., 1995; Estrella and Morrissey, 1997; Watson et al., 1999; Watson and Jury, 2013; Jury and Watson, 2013), and wave surge and storms (Goldstein, 2012; Goldstein and Watson, 2015). At our study site along the coast of NH, USA, probably the strongest predictor of lobster distribution and density is water temperature. The thermosensitivity of American lobsters allows them to detect, and thus avoid, extreme temperatures (Crossin et al., 1998; Jury and Watson, 2000), as well as move to areas that are at their preferred temperature of ~16 °C (Crossin et al., 1998). As a result, lobsters tend to move inshore in the spring/summer because water temperatures tend to be higher along the coast and then, in the fall, move offshore as inshore temperatures drop. This, in part, gives rise to the large seasonal fluctuations in lobster density documented in inshore NH, USA waters (Fig. 2; Watson and Jury, 2013).

In this study, lobster movements to coastal waters in the spring were correlated with increasing water temperatures and, likewise, diminishing lobster densities were associated with decreasing inshore temperatures in the fall (Fig. 2). The density of lobsters and water temperatures off the coast began to increase in May or June of each year and peaked between August and September, before decreasing in the fall; a pattern that has been observed in previous studies at this same study site (Jury et al., 2001; Watson and Jury, 2013). The relationship between lobster catch and water temperature is a longstanding observation, and there have been many explanations put forth to explain this phenomenon. The two most commonly accepted are: (1) lobster metabolism and activity levels increase as water temperatures rise, causing them to seek food and to enter traps and; (2) lobsters move into areas that are at their optimal water temperature, which increases lobster density and catch (Drinkwater et al., 2006; Watson and Jury, 2013; Jury and Watson, 2013). The use of SCUBA surveys in this study clearly demonstrated that lobster density was very closely correlated with seasonal changes in water temperature, as well as CPUE. But, because of the impacts of water temperature on lobster metabolism and mobility it is impossible, at this time, to determine which of these temperature-dependent factors were most responsible for causing the strong correlation between warmer water and increased catch.

Due to lobster mobility and large seasonal fluctuations in lobster abundance, managing the lobster fishery can be especially challenging. The use of dive surveys is costly, limited in spatial coverage, and potentially biased. Standard traps, on the other hand, are very useful for collecting fishery-dependent and fishery-independent information. However, the correlation between catch in standard traps and lobster density is generally poor and requires very large sample sizes (Jury et al., 2001; Watson and Jury, 2013). Therefore, additional fishery-independent sampling methods, such as ventless trap surveys, have been implemented on a regular basis by appropriate Canadian, and New England state, agencies (DMR, 2011).

4.2. Ventless vs. standard traps

At the study site used for this investigation, there were relatively few legal-sized lobsters, based on SCUBA surveys. Therefore, most of the lobsters collected during this study were of sublegal size (CL < 83 mm). The mean size of lobsters captured by SCUBA divers (48.06 ± 0.90 mm CL) was significantly smaller than the average size of lobsters captured in either type of trap. This was likely due to the fact that the traps failed to retain most lobsters on the small end of the size frequency range because they were able to escape through holes in the wire mesh (Fig. 3). In both standard and ventless traps, video surveillance showed many lobsters escaping through the trap mesh and entrance (Clark et al., in preparation). This is likely, in part, the reason why these two trap types collectively caught lobsters of a similar size composition.

As expected, based on previous studies (Glenn et al., 2007; Courchene and Stokesbury, 2011) ventless traps caught significantly more lobsters than standard traps in all months and at all lobster densities. Based on observations of both trap types using time-lapse video cameras, the major difference between these traps was that very few lobsters escaped from ventless traps. Despite the fact that they could escape through the trap mesh and entrance (Jury et al., 2001), they tended to accumulate in the parlor of ventless traps (Clark et al., in preparation), for reasons that are still being investigated.

Both types of traps caught more male lobsters than females; between 72 and 87% of the lobsters captured in 2010 and 2011 were male. These data are consistent with previous findings for ventless traps, demonstrating that male lobsters tend to represent a larger proportion of catch (Tremblay et al., 2006; Courchene and Stokesbury, 2011). This skewed sex ratio could be due to differential catchability of male vs. female lobsters, or it could represent the actual sex ratio in this area. Because SCUBA surveys yielded results that were also skewed towards males, it appears that, at least in this study, catch in ventless traps accurately represented the sex ratio of the population on the bottom. It is possible that there are more males in this area because they tend to prefer warmer water and thus aggregate in warmer, shallower waters in comparison to females (Watson et al., 1999; Jury and Watson, 2013).

4.3. The relationship between catch and lobster density

One of the major goals of this study was to determine which type of trap provided the best index of lobster density on the bottom (estimated using SCUBA surveys).

In 2010, lobster density increased ~5-fold, from 0.03 ± 0.005 lobsters/m^2 in June to 0.16 ± 0.004 lobsters/m^2 in September, while in 2011 it fluctuated between 0.001 ± 0.001 lobsters/m^2 in May and 0.11 ± 0.028 lobsters/m^2 in August (Fig. 2). In both years the relationship between catch and density was very poor for standard traps, at all soak times (Fig. 8B). For ventless traps, as lobster density increased, so did catch at all soak times (Fig. 8A). However, catch after certain soak times (16, 24, 48 h) provided a better index of lobster density on the bottom than other soak times, with 48-h CPUE providing the strongest correlation. It should be noted that this correlation might be even stronger if only "catchable" lobsters were taken into account. As illustrated in Fig. 3, many of the lobsters counted by SCUBA divers on the bottom were not captured in traps, either because they never entered the traps, or they readily escaped through the trap mesh (Clark et al., in preparation).

4.4. *Trap saturation*

While gear saturation occurs in many fisheries assessments, its effects are not well understood (Miller, 1979; Barber and Cobb, 2009; Stoner, 2004). The saturation curves presented in this study demonstrated how catch in ventless traps tended to increase rapidly during the first 16 to 24 h of a soak before beginning to plateau (Fig. 5). Previous studies examining the relationship between soak time and catch in standard lobster traps yielded similar curves, illustrating that this phenomenon is a common characteristic of lobster trap dynamics (Auster, 1985). In the present study standard trap CPUE was not significantly different across all soak periods (Fig. 5) and tended to plateau starting 4 h after deployment (Fig. 6). This is consistent with data from two previous studies that focused on standard traps in the same area (Jury et al., 2001; Watson and Jury, 2013). This situation is likely different in areas with more legal lobsters that tend to accumulate in traps, in contrast to this study site. Moreover, multiple studies have demonstrated that larger lobsters tend to enter traps later in a soak period (Jury et al., 2001; Watson and Jury, 2013), and thus, for a commercial lobstermen, it may make sense to fish traps for relatively long soak times in order to optimize catch of larger lobsters.

In contrast to standard traps, ventless traps saturated between approximately 16 and 24 h. Thus, from a practical perspective, there is no apparent advantage to collecting data from ventless traps for more than 24 h, except perhaps if the goal is to collect data on larger lobsters (Jury et al., 2001; Watson and Jury, 2013). Moreover, our data indicate that the relationship between lobster density and catch is weakest at the highest lobster densities, so longer soak times might make this even more problematic.

The three main factors that have been proposed to give rise to trap saturation are: (1) traps fill with lobsters, to the point where they cannot hold anymore (Prchalová et al., 2011); (2) once some lobsters get into a trap, especially larger lobsters, they discourage other lobsters from entering (Richards et al., 1983; Jury et al., 2001; Watson and Jury, 2013) and; (3) as bait deteriorates, it stops attracting lobsters (Karnofsky and Price, 1989). These studies were conducted using standard traps only, but data obtained in the present study do not support the first two hypotheses for ventless traps. First, at all densities tested, ventless traps saturated, but at different final catch values. This indicates that saturation was not a function of the number of lobsters in the trap, because if that were the case, then all of the traps would have saturated at the same CPUE value. This is not to say that in areas with a high density of lobsters, especially large ones, ventless traps will not reach a point where CPUE levels off because the traps simply cannot hold additional animals. For example, in some locations in Massachusetts, ventless traps of similar design have been reported to catch up to 80 lobsters (Tracy Pugh, personal communication), well above the maximum of 49 lobsters captured in this study. However, in terms of the data obtained in this study, it does not appear as though traps reached a point where they could not catch more lobsters due to exceeded trap capacity.

Several studies with lobsters and other crustaceans have provided observations and data suggesting that animals in a trap, through antagonistic interactions, reduce the rate of entry of additional animals (Richards et al., 1983; Addison, 1995; Addison and Bannister, 1998; Jury et al., 2001; Barber and Cobb, 2009; Watson and Jury, 2013). While underwater surveillance footage demonstrates that these types of interactions also occurred in this study (Clark et al., in preparation), it was not evident that they limited catch, at least in ventless traps. If interactions limited catch, then one might expect these interactions to be very intense at high densities and that subsequent CPUE would be at its maximal. However, as explained above, this scenario did not occur in this study. The maximum CPUE tended to increase as density increased under the conditions tested.

Currently, the two hypotheses that we favor are bait deterioration and lobster removal from the area fished by traps. Previous studies have demonstrated that the release of attractants from bait (herring) declines rapidly during the first 24 h (Daniel and Bayer, 1987), and thus ventless traps may have saturated due to a reduction in bait attractiveness and consequently the rate of entry into the traps (Miller, 1990). Also, because the ventless traps retained so many lobsters, in contrast to standard traps, it is possible that most of the catchable lobsters in the area surrounding the trap were captured after 16–24 h so that after this time point the rate of entries and exits were equivalent. Studies are currently underway to test both of these possibilities.

One of our original hypotheses was that traps would saturate at a faster rate when the density of lobsters on the bottom was high. However, we found that ventless traps saturated at approximately the same time at different densities, and that the catch at saturation (maximal catch) increased with higher densities. To investigate this further, catch data were binned into two groups based on the lobster density when they were collected (0 to 0.4 lobsters/m^2 and 1 to 1.5 lobsters/m^2). Catch for both density groups began to saturate within 16 to 24 h (Figs. 5 and 6). Thus, under our conditions the time to reach trap saturation does not appear to be a useful index of lobster density on the bottom. In contrast, the maximum catch in ventless traps did correlate with lobster density. CPUE ranged from 19.4 ± 1.9 at the low densities to 31.6 ± 3.1 at high densities (Fig. 7). At low densities, lobsters entered ventless traps at a rate of approximately 0.82 lobsters/h for the first 16–24 h of a soak, after which the catch rate decreased by about 10-fold, to 0.09 lobsters/h. The initial entry rate for lobsters at higher densities was 1.02 lobsters/h, before leveling off at 0.03 lobsters/h. Therefore, both rate of catch, in lobsters/h, within the first 24 h, or maximal catch after 24 h, could provide useful indices of lobster abundance.

5. Conclusions

This study has demonstrated that ventless traps have the potential to provide a more accurate estimate of the lobster population on the bottom in any given location than standard traps. Importantly, it demonstrates that catch in ventless traps correlates fairly well with lobster density. Moreover, our findings provide some guidance regarding which soak times may provide the most accurate indices of abundance. These data also show that trap saturation is a very important factor to consider when assessing catch in both ventless and standard traps. Additional studies are underway to address the potential causes of trap saturation, particularly among ventless traps, with the expectation that modifications in the ventless trap survey protocol could improve the assessment of lobster populations on the bottom.

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