Assessing the Applicability of Computer Aided Photo-identification for Pinniped Studies Through the Determination of Site Fidelity in Long Island, NY Harbor Seals (Phoca Vitulina Concolor)

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ASSESSING THE APPLICABILITY OF COMPUTER AIDED PHOTO-IDENTIFICATION FOR PINNIPED STUDIES THROUGH THE DETERMINATION OF SITE FIDELITY IN LONG ISLAND, NY HARBOR SEALS (PHOCA VITULINA CONCOLOR)

By

Meaghan McCormack

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CONCOLOR)

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Studying the population parameters of marine mammals requires that individuals be identified both spatially and temporally. Traditionally, to identify individuals in the field, animals have been captured and physically marked with a unique feature, allowing the individual to be identified in the future. This method known as Capture-Mark-Recapture (CMR) has been widely utilized to analyze marine mammal populations. While quite effective, traditional CMR is invasive and poses potential risk for both animals and researchers. More recently, with advanced technology and camera equipment, a far less invasive and more cost-effective method of Photo-identification based Mark Recapture has been developed (PMR).

To assess the efficacy of computer-aided matching software and the applicability of such software for future pinniped studies, a photographic-based mark-recapture study was conducted across the 2011-2014 harbor seal seasons using both manual and computer-aided methods to determine if the Long Island, NY population display site fidelity, in that they return to the same haul-out location over multiple seasons. Additionally, manual and computer methods were compared for accuracy and their potential use in future pinniped studies.
Results indicated that some Long Island harbor seals show site fidelity, returning to the same haul-out locations over multiple seasons. Both methods were successful at identifying and organizing capture histories of harbor seals. The computer aided method was found to be slightly more accurate, resulting in higher re-sighing rates and greater numbers of identifiable individuals. However, both the manual and computer aided methods were time consuming. Automating pre-processing steps in the computer aided methods will aid in minimizing effort associated with this method. Likewise, the development of a similarity coefficient threshold for viewing potential matches will minimize effort. Errors, particularly false negative errors, remain an issue in both methods. Future research on computer matching software should focus on minimizing effort, largely through the automating of pre-processing steps, development of a similarity coefficient threshold, and reducing false negative errors. Further advancements in computer aided matching software will enhance our ability to study the population parameters of pinnipeds via haul out and rookery sites both accurately and effectively.
DEDICATION

I would like to dedicate this thesis to my parents who have supported me throughout my education and in all aspects of my life. Thank you for supporting me from the very beginning; you support does not go unnoticed.
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Chapter 1 Introduction

Studying the population dynamics, site utilization, and movement patterns of animal populations requires that individuals be tracked both spatially and temporally (Beaumont & Goold, 2007). This can be an extremely difficult task, especially for cryptic species, including marine mammals. Challenges in studying marine mammals relate to access and scale. They live entirely (cetaceans and sirenians) or most of their lives in water (pinnipeds) and inhabit large geographical areas (Boyd, Bowen & Iverson, 2010). Pinnipeds are a unique case in that although they spend a large portion of their lives in water, not visible to us, they also regularly haul-out on land. Such haul-out locations provide researchers opportunities to analyze seal behavior and population parameters.

North Atlantic Harbor Seal

This study focused on harbor seals, the most widespread of the pinniped species. Harbor seals are found in all near shore waters of the North Atlantic Ocean, from about 30°N to 80°N (Katona, Rough & Richardson, 1993). The North Atlantic Stock is further differentiated into the Western North Atlantic (WNA) and Eastern North Atlantic Stocks (ENA) (Waring et al., 2010). While the geographic boundaries dividing the eastern and western North Atlantic populations are undetermined, Stanley et al. (1996) found that WNA and ENA harbor seals were highly differentiated based on differences in mitochondrial DNA sequences. In the Western North Atlantic, harbor seals are found from Eastern Canada to New Jersey (Katona et al., 1993). Harbor seals are considered non-migratory species, although they do display seasonal movements related to breeding, molting and foraging patterns (Waring et al., 2010).
Harbor seals can inhabit northern coastal waters of Maine and south-east Canada year round. However, some harbor seals display seasonal migrations patterns, traveling south in the fall-winter months to southern New England, New York and New Jersey. In these warmer waters, spanning, harbor seals are seasonal inhabitants, occupying coastal waters from September through May (Waring et al., 2006). A reverse northern movement is apparent, prior to the pupping season, in May and June, with seals traveling back north to Northern New England and Canada (Fig.1) Pupping occurs in summer, and molting occurs in early fall in these more northern locations (Waring et al., 2010). Throughout this seasonal migration, harbor seals regularly haul out, making them accessible to researchers.

**Harbor Seal Haul-Out Behavior**

Pinnipeds haul out for a variety of reasons including resting, rearing and nursing pups, thermoregulation, avoiding predators, and molting (Watts, 1992). Haul out sites have been shown to be tremendously important. For example, McConelll et al. (1999) determined that grey seals spend a significant amount of time (40%) around specific haul out sites, which were often more than 50km away from foraging sites. Some adult grey seals have been monitored traveling over 100km between haul out sites (McConnell et al., 1999). Such high travel costs and reduced foraging opportunities indicate that the benefits of hauling out are substantial and that haul-out site selection is extremely important to overall fitness. Seals spend approximately half of their time hauled out on land. A seals’ energy budget while hauled out is dominated by resting and scanning behaviors. Harbor seals, like other phocids, can achieve low wave sleep while submerged but can only achieve rapid eye movement sleep while at the surface of the
water or hauled out (Ridgeway et al., 1978; Da Silva & Terhune, 1988). Thus, haul out sites are important for adequate rest; however, while hauled, seals must also be aware of their surroundings and exposure to potential threats. As such, another common haul out behavior is scanning. Scanning is typically defined by an increase in visual field; it is often categorized by a seal raising its head from the resting position, moving its head horizontally for a time and returning its head to the resting position (Terhune & Brillant, 1996). Resting and scanning behaviors are incompatible, and animals must balance the need for rest with the need to be alert to potential threats. One possible explanation for how seals reconcile these demands is by hauling out in groups as an anti-predator strategy.

When harbor seals are hauled out, they form unstable groups, which are not thought to driven by social behaviors (Da Silva & Terhune, 1988; Godsell, 1987). Early hypotheses considered that largely solitary seals formed haul out aggregations as a response to a shortage of suitable space available or haul-out sites. However, groups often arise even when there appears to be ample, suitable haul-out sites and space. It has been determined that, similar to the behavior in flocking birds, as seal group size increases, individuals spend less time scanning and more time resting (Terhune, 1985; Da Silva & Terhune, 1988). While individual vigilance decreases, the vigilance of the group is increased, and seals are alerted to potential threats simply by other individuals flushing the haul-out site. This differs from anti-predator strategies in stable groups formed by social animals such as meerkats, Suricata suricatta, where scanning behavior is reduced for all but a few individuals who actively alert other members of the danger (Turnhue & Brillant, 1996). This is termed the ‘watchman’s song hypothesis’. There has been no
evidence to indicate that harbor seals coordinate their levels of vigilance, as such coordination would be difficult considering these are non-social groups without permanent members (Terhune & Brillant, 1996; Wickler, 1985). Additionally, seals near the periphery display higher levels of vigilance than seals at the center, likely because animals residing near the periphery have a higher chance of being preyed upon and must remain more vigilant (Terhune & Brillant, 1996). Harbor seals were also determined to be more vigilant when they first arrived at the site, often utilizing the only available space at the periphery of the aggregation. Therefore, increased vigilance near the periphery may be related to increase predation risk and simply being a new comer to the haul-out site (Terhune & Brillant, 1996). The spacing and orientation of seals when hauled out also indicates that haul out aggregations are a result of an anti-predator strategies. Seals position themselves at least one body length apart from one another and orient toward the water. This facilitates a quick escape, while avoiding collisions, in the event of a disturbance (Terhune & Brillant, 1996).

As outlined above, there are numerous factors that can be attributed to harbor seal haul-out behavior. Theoretically, harbor seals should spend the maximum amount of time hauled out (Watts, 1992). Immersion is energetically costly, seals cannot rest and must contest with wave energy when submerged. Seals are also at risk of being preyed upon by aquatic predators when at sea. Additionally, it has been shown that peripheral tissues of harbor seals do not metabolize appropriately at temperatures below 17°C. Since the skin temperature while submerged is often close to ambient temperatures, that are below 17°C, regular haul outs would be beneficial in maintaining adequate skin health (Watts, 1992; Feltz & Fey, 1966). Considering the benefits of hauling out, it
would be reasonable to presume that harbor seals should spend all their time during the
day and enter the water at night to forage, when foraging efficiency is greatest (Watts,
1992). While harbor seals are generally nocturnal foragers, they do not remain hauled
throughout the daylight hours, and there is reason to believe that this is a result of
thermoregulatory behavior (Watts, 1992).

Pinnipeds are semi-aquatic marine mammals and therefore, need to reconcile the
demands both marine and terrestrial thermoregulatory needs. Water conducts heat 25x
more rapidly than air. In order to reduce heat loss while submerged, pinnipeds utilize a
layer of blubber which impedes heat flow. This insulating mechanism, although
productive while submerged, can be detrimental to seals when they are hauled out on
land, causing hyperthermia. Seals can only loose heat through areas with little no
blubber- largely the through the flippers and head. The only ways to lose heat in such
situations is for wet seals to lose heat through evaporative cooling or for dry or wet seals
to stay in in contact with cool substrate, losing heat through conduction (Watts, 1992). In
addition to the limitations regarding the dumping excess heat, seals are also at risk of
taking on too much heat. Depending on solar radiation, the pelage and skin can act as a
heat trap, with heat reflected by hairs and absorbed by darkly pigmented skin (Watts,
1992). Harbor seals are sensitive to overheating and may increase body temperature at
rates of 1°C per fifteen min and, therefore, avoid situations in which hauling out would
greatly increase core body temperature. The thermoregulatory mechanisms that allow
seals to maintain an aquatic existence preclude seals from spending too much time hauled
out for risk of hyperthermia. Thermal constraints may explain site specific differences in
daily haul-out time between sites as well seasonal changes in haul-out behavior.
Haul-out behavior is also dictated by life history events, including breeding. Seasonal changes in haul-out behavior in response to breeding results in skewed population haul out proportions. Just prior to giving birth, females will haul out in anticipation of parturition. These haul-out sites, known as nursery sites, are ideal for newborn pups having gently sloping substrates and calm water. Mother-pup pairs constitute the majority of animals at nursery sites (Kovacs et al., 1990). Three lactation strategies have been suggested for three pinniped families. Phocids generally build up fat reserves so they can fast during lactation, providing pups with a high fat content milk over a short period of time. Otarids have an extended period of lactation, providing milk with lower fat content and alternating between lactating and foraging. The Odobenidae have an extended period of lactation, and the pup accompanies the female while foraging, so suckling and feeding can occur at once. Harbor seals seem to have a strategy in between that of phocids and otarids. Studies have shown that in the early stages of caring for their pup, females will spend a larger amount of time hauled out in order to lactate, which often results in unequal sex ratio of hauled out adults (Godsell, 1988). That being said, there is considerable evidence that female harbor seals spend a significant amount of time foraging during the later stages of the maternal care period (Thompson et al., 1996). There is also evidence that pups may accompany females on foraging trips like the odobenidae (Thompson et al., 1996). These foraging trips are often shorter and occur within a smaller range compared to trips that are not associated females caring for pups. A final variable that influences female haul-out is the level of stored fat reserved prior to giving birth. Larger females can rely on stored fat reserves and spend less time foraging.
While females are spending much of their time hauled out caring for pups, male behavior during the breeding season also influences the proportion of the population that is hauled out. About half of pinniped species are land breeding species. Large bodies and limited mobility on land predispose pinnipeds to mating strategies in which males maximize reproductive success by defending territories (and the resources needed by females, e.g. pupping sites) or defending females. The remaining half of all pinniped species, including harbor seals, are aquatic breeding pinnipeds. Reproductive strategies utilized in land breeding species, including territorial defense, and female defense are not successful among aquatic breeding species, as pinnipeds have greater mobility in water, and females are widely dispersed. Therefore, divergent strategies including common lekking (a strategy in which males gather perform competitive displays), roving (a strategy in which males roam looking for receptive females), and defending territories (e.g. defending foraging corridors) have been suggested as possible strategies utilized by aquatic breeding species (Boness et al., 2006). All three strategies have been observed in harbor seals, with lekking identified as the most prominent strategy observed.

Males have been shown to spend considerable time around nursery sites and traffic corridors towards the end of the lactation period. Once the female has weaned her pup, she will enter estrus. During this time, males gather, emit acoustical underwater displays and display male-male competitive behaviors near these female ‘hot spots’. Such behavior is similar to lekking behaviors in other species such as birds, in which males aggregate and display, which results in some level of female choice (Hayes et al., 2004). Female choice is also thought to be a factor, evidenced by the fact that males patrolling areas closest nursery sites do not sire more offspring compared to those
patrolling areas farther from nursery sites (Boness et al., 2006). Changes in behavior during the breeding season substantially alter haul-out behavior and must be considered when determining population parameters based on haul-out surveys.

While the general explanations for haul-out behavior are well established, the mechanisms driving haul-out site selection are less certain. The common variables that have been proposed as influencing site selection include, tidal conditions, time of day, distance to prey, protection from wind, and distance from disturbance (Montgomery, Hoef, & Boveng, 2007). These variables vary both spatially and temporally. The two factors that have most commonly been cited across studies as significantly affecting haul out behavior are tidal conditions and disturbance. Seals tend to haul out at low tide and at sites that are far from potential disturbances (Nordstrom, 2002). Therefore, different environmental conditions will result in differing haul-out behavior between populations of seals, and seasonal changes in environmental conditions may influence the haul-out behavior within a population of seals. Such conditions must be taken into consideration when designing surveys and analyzing findings.

The choice of haul-out site is fundamental to survival. The use of geospatial modeling has greatly increased our understanding of what environmental factors drive haul-out site choice and how habitat selection varies spatially (Montgomery et al., 2007). Determining the ideal conditions for specific populations can aid in determining what ideal haul-out proportions of a population are, and in turn, increase the accuracy of population studies and aid in management decisions (Simpkins et al., 2003). Harbor seals are the most widely distributed of the pinniped species, occupying a variety of habitats, which allows for the comparison of site choice between different habitats.
Particularly important from a management perspective is the determination of site fidelity among populations of pinnipeds.

**Site Fidelity in Harbor Seals and Management Implications**

Site fidelity, that is the return of an animal to a previously utilized location, is an important component of animal behavior and can result from social interactions, territorialism, and/or the efficient exploitation of scattered resources (Giuggioli & Bartumeus, 2012). It is often, but not necessarily, tied to breeding behavior. Site fidelity is also an example of an animals’ efficient exploitation of heterogeneous landscape, taking advantage of scattered resources, be it food, mates and/or protection (Giuggioli & Bartumeus, 2012). Studying site fidelity allows us to better understand the underlying behavioral mechanisms at play that dictate site choice.

Site fidelity related to specific haul-out locations has been identified across multiple pinniped species, including harbor seals (Hoezel, 2009). In harbor seals, site fidelity is most commonly associated with breeding and foraging behavior (Kelly *et al.*, 2010). Site fidelity as a result of breeding behavior was studied by Härkönen & Harding (2001) by tracking freeze branded harbor seals pups in Sweden over 14 years. They determined that none of the 164 pups were found more than 32km of where they were branded as pups. Site fidelity as a result of foraging behavior has been studied by Bjørge *et al.*, (1995) in which 13 harbor seals were tracked in Norway using radio VHF telemetry during the summer season, and they determined that, while individual seals utilized different types of foraging habitat, all individuals repeatedly used the same foraging location throughout the season.
Sustained patterns of site use have various consequences for management. First, monitoring of anthropogenic disturbances is necessary to maintain healthy populations. Harbor seals have been shown to exhibit varying responses to anthropogenic disturbance, including temporary abandonment of haul-out sites, permanent abandonment of haul-out sites, and habituation (Grigg et al., 2012). Temporary abandonment of haul-out site is commonly associated with pedestrian boat and beach traffic, as well as a result of eco-tours. Henry & Hammill (2001) measured harbor seal responses to the presence of power boats, sailboats and kayaks in the St. Lawrence estuary and found that the most common cause of abandonment was kayak disturbance. While kayaking is largely considered a low impact activity, the authors theorized that because kayakers had quiet approaches, seals were startled by the sudden close proximity of kayaks, which caused the seals to flush to the haul-out. Alert behavior, including increased time scanning, also increased in response to levels of disturbance, which increases energy demands and may decrease overall fitness. Seal behavior varied over seasons, with seals being less likely to be disturbed and enter the water during the molting season. Continued use and haul-out numbers throughout the year suggest that the site is only temporarily abandoned in times of high disturbance (Henry & Hammill, 2001). Other populations of harbor seals have permanently abandoned previously utilized haul-out sites in response to human disturbance. For instance, Becker, Press & Allen (2011) reported data that helps to explain the long term spatial shifts in haul-out harbor seal pupping in response to shellfish aquaculture operations in north-central California. The study showed that continuous disturbance from anthropogenic sources, such as aquaculture activities, differs from discrete forms of human disturbances, such as hikers or kayakers, and can result in
permanent abandonment of haul-out sites. Alternatively, some harbor seal populations appear to show little behavioral changes in response to high levels of anthropogenic disturbance. For example, harbor seals in San Francisco Bay have demonstrated high levels of habituation to human disturbance, continuing to utilize foraging and haul-out locations heavily influenced by recreational use, boating and fishing activities (Grigg et al., 2012). Such overlap between humans and seal populations is likely to increase in the future. If seals do not find suitable habitat, they could be at risk. In this case, the development of a protected area may be necessary.

A second management implication as a result of seals displaying site fidelity deals with environmental concerns. First, it is necessary to monitor disease. Disease outbreaks, including those of phocine distemper virus (PDV), can result in large scale mortalities and be particularly devastating for populations displaying site fidelity over small geographic areas (Olsen et al., 2013). For example, in 1988 an epidemic outbreak of PDV claimed over 23,000 European harbor seals, nearly 60% of the North Seal harbor seal population (Härkönen et al., 2006). In 2002, over 30,000 harbor seals died as a result of being infected with a similar strain of morbillivirus identified as canine distemper virus (Härkönen et al., 2006). Harbor seal populations in this area have been shown to display season site fidelity, relating to breeding behavior, particularly in the summer months. Populations as a result are genetically distinct despite relatively close geographic location. However, outside of the breeding season, seals expand their home range and may interact with other populations (Olsen et al., 2013). It is thought that this is how the phocine distemper virus was so devastating to localized populations but also was transferred between distinct populations. Likewise, animals that display site fidelity
are also at risk for other environmental stressors including decreases in water quality, decreases in prey availability, and increased presence of contaminants, including organochlorines, PCBs, heavy metals and harmful algal blooms.

Lastly, site fidelity has been shown to be correlated with the genetic isolation of seal populations. Seals aggregate in haul-out groups along the coast. The absence of physical barriers between these aggregations and given that seals have been documented travel far distances, it was originally presumed that there was genetic interchange between these populations. However, genetic analysis revealed that increased geographic distance was correlated with increase genetic differentiation (Stanley et al., 1996). These findings could not be explained by distance alone, as seals were shown to be capable of migrating at greater distances than those which separated populations. Therefore, it was presumed that a behavioral mechanism must be at play to hamper gene flow, such as a specific form of site fidelity, called philopatry, in which seals return to their natal site to breed (Härkönen et al., 2006). In such instances these populations should be treated as separate ecological stocks (Karlsson et al., 2005). In order to determine a population’s spatial use patterns, and if populations display site fidelity, individuals must be tracked over relevant spatial and temporal scales.

**Photo-identification based Capture Mark Recapture**

In order to determine the importance of specific haul out locations and the possibility of site fidelity, individual seals must be identified over multiple seasons. The inability to capture and follow large numbers of seals in the wild has been a significant hindrance to furthering our understanding of pinniped species (Loughlin, 2010). It is only recently that we have expanded research beyond focusing on dead specimens to include
animals that have been captured, marked and followed – a method coined Capture-Mark-
Recapture (CMR) (Loughlin et al., 2010). Previously utilized CMR methods have relied
on manually capturing and artificially marking animals via hot iron branding, freeze
branding and/or flipper tagging (Beaumont & Goold, 2007). Though efficiently utilized,
tags are costly and prone to lack of permanence over time (Arntezen et al., 2004). Most
importantly, these methods are invasive and result in stress to the animal, as well as
potential injury to researchers (Beaumont & Goold, 2007). In response to growing
concerns over the associated negative impact of physical CMR studies, researchers
sought less invasive marking techniques.

Identifying animals based on natural markings provides a feasible alternative to
physical tags. Advances in camera equipment and technology has allowed for a far less
invasive method of CMR involving photo-identification based capture-mark-recapture
(PMR) to be successfully utilized (Hastings, Hiby, & Small, 2008). Photo-ID based
Capture-Mark-Recapture (PMR) relies on re-sighting of animals with naturally occurring
markings to determine population parameters, including movement patterns, site fidelity,
and populations size (Karlsson et al., 2005). Natural markings on individuals are
“captured” photographically and stored in a digital catalogue. Individuals recaptured
later can be matched with earlier photos of that animal based on its’ unique
characteristics, creating a unique capture history for that individual (Speed, Meekan, &
Bradshaw, 2007). The use of photo-identification based on natural marking provides
many advantages.

Photo-identification makes it possible to identify individuals over multiple years.
In most cases, markings are stable over time, which nearly eliminates the risk of ‘tag’
loss prevalent in traditional CMR studies (Beaumont & Goold, 2007). For example, harbor seals display unique patterns of spots and rings overlain on contrasting light and dark pelage which have been shown to be stable over time (Yochem et al., 1990). Natural marking also tend to be universal within a species and allow researchers to “capture” a far greater number of animals than traditional tagging methods (Arzoumanian, Holmberg & Norman, 2005). The use of photo-identification is also very cost effective, relying solely on the use of high quality photographic materials and allows researchers to “capture” many animals at once (Beaumont & Goold, 2007). The use of photo-identification based on natural markings is the most appropriate choice in circumstances where physical capture is difficult or impossible. It also may be the only appropriate choice when dealing with endangered species, in order to minimize potential disturbance. (Stevick et al., 2001).

For these reasons, photo-identification has become the leading method utilized in wildlife tagging studies. Photographic methodologies can be broken down into two categories, active and passive, based on the level of potential disturbance to the animal (Sears et al., 1990). Passive methods include, aerial surveys (e.g. whales, Sears et al., 1990) and infrared cameras, as they are unlikely to disturb target individuals (e.g. bobcats, Heilbrun et al., 2003). Active methods include physically approaching an animal on land or in a boat in order to take a photograph, as they are more likely to cause potential disturbance of target individuals (Gilkinson et al., 2007). Pinniped photo-identification, utilized in the present study, is largely a passive approach, as it occurs on the main beach while seals are hauled out on nearby sand banks. Surveying from an adequate distance from the sandbar, rarely results in disturbance of seals. However, large
and vociferous crowds gathered during seal walks do have the potential to alter seal behavior. Both passive and active photo-identification methods require that images are stored in a library to later be visually matched and to develop individual capture histories.

**Manual Photo-identification Techniques**

The most common method of photo-identification involves manually matching every image in the library, unassisted by computer matching software (although images may be inspected using a computer). Advantage to manual matching methods include minimal cost and minimal training of photo analysts. However, a certain amount of time may be required for photo analysts to gain familiarity with the population in order to avoid errors in matching. Manual matching is ideal for small (<200) to medium (<850) catalogues (Hammond, Mizaroch & Donovan, 1990). However, while it is possible to manage small databases of images, the task of manually matching individuals becomes increasingly time consuming and error prone as library catalogues grow (Arntzen et al., 2004). In response, many photographic studies add additional steps to the pre-sorting of images, in which images are given alphanumeric names according to dates of capture and categorize individuals based on physical appearance using keywords to aid in the matching process. For example, harbor seals may be named based on their sighting date and keywords associated color phase, spot density and/or spot complexity (ex: unnamed-2011-02-01A “color phase=dark”). In this way when that individual is compared to other individuals in the catalogue the search can be narrowed down to other individuals that have similar keywords which may reduce matching effort. This additional step lengthens the already tedious process of manual identification. Eventually, the sheer size of the database makes it nearly impossible to manage manually, and many researches turn
to computer assisted, semi-automated matching software to save time, minimize effort and cost, and increase accuracy.

**Computer Aided Photo-Identification Techniques**

Computer aided techniques are semi-automated in that they require manual importing of photos, pre-processing of images, and visual confirmation of potential matches by the photo-analyst. The part of the process that does not require manual input is the batch compare stage, which expedites the matching process and leads to the greatest potential benefit of computer aided techniques in terms of reduced matching effort. Matching software can be categorized as either being metric or non-metric. Metric based systems rely on metrical analyses of extracts taken from features such as a dorsal fin, fluke patterns, or pelage coloration (Adams *et al.*, 2006). In contrast, non-metric matching software use categorical descriptions of features to aid in the matching process (e.g. Finbase using descriptions of dorsal fins). Such descriptive features are stored in a database and can be used by the photo-analyst to aid in matching individuals. Non-metric systems tend to be less dependent on photo quality, but they are often criticized for being subjective, relying on photo analysts to input categorical data (Adams *et al.*, 2006). In both metric and non-metric systems there are three main phases.

First, photos are imported into the computer software. This may involve digitizing, scanning, or simply downloading photos. Some photos may need to be cropped or lightened to be useful in matching software. These steps require human input as they are not automated. Next, in metric systems, an extract is taken to describe the morphological features (e.g. scarring in manatees) or patterns of pigmentation (e.g. pelage patterns in harbor seals). In non-metric systems, images are qualitatively
described by photo analysts (e.g. describing the position of notches in the dorsal fin of dolphins).

Second, images are compared to all other images and ranked as potential matches. In metric systems, this is accomplished through the use of pattern recognition algorithms. In many cases, a similarity coefficient is determined to identify where in a list of potential matches, true matches occur. Beyond the defined similarity coefficient, it is estimated that no true matches will occur and such potential matches are disregarded. Both matching algorithms and similarity coefficients differ between matching programs and are largely species specific. Non-metric systems generate a list of potential matches based on the number of similar categories and/or characteristics that two images share.

Finally, researchers manually make the final decision to verify or reject potential matches. Ideally, the computer has facilitated the matching process by reducing the amount of photos from the library that researchers need to visually inspect. For datasets with known matches, efficiency and accuracy of the programs can be reported by where the match was found relative to the similarity coefficient and number of false positive and false negative errors.

**Capture Mark Recapture Assumptions**

In both manual and computer aided photo-identification studies, researchers must take careful consideration of the assumption made by CMR studies, that all animals have equal probability of being captured, marked, and later identified for each capture event. To meet this assumption, all animals must have equal probability of both being sighted and captured, and in the case of photographic based studies, being photographed.
This assumption is not always met. Researchers should be aware and report instances in the study in which these conditions may not be met. Behaviorally, some animals may be more difficult to photograph. Additionally, certain life history events may dictate behaviors that preclude this assumption from being met. For example, during harbor seals’ breeding season, there is a disproportionate number of females hauled out while they are caring for pups. The distinctiveness of individual marks also effects this assumption. Certain animals have more distinct marks than others and are thus, more likely to be captured and recognized via photo-identification (Hammond, Mizroch & Donavon, 1990). Harbor seal pelage is variable, with some individuals displaying more unique characteristics.

Final factors that affect the likelihood that animals will have equal probability of being captured are photo quality and measurability. If photo quality is poor there will a lower detection rate. Photo quality is loosely defined by factors including clarity, focus, resolution, background noise, contrast, and glare (Hammond 1986; Arzoumanian, Holberg & Norman, 2005). Photo quality can only be minimally controlled for in the natural environment. Since photographic quality is inextricably linked to the distinctiveness of marks, as photo quality decreases, the distinctness of marks decreases (Friday et al., 2000). Photo quality is often assessed as images are imported into databases. While computer assisted matching programs are often very sensitive to decreases in photo quality, manual identification is often still possible with low quality photos. Despite the level of quality, researchers should report photo quality as it can lead to errors or bias. The final factor to consider deals with measurability, in particular our ability to identify a pattern that exists on a 3 dimensional animal from a photograph
(Gunnlaugsson & Sigurjoinsson, 1990). At any moment a camera is not perpendicular to the animal, and patterns can be distorted (Speed, 2007). To minimize the risk of missing a match due to measurability, photos are taken from multiple angles and and/or a computerized system developed to superimpose a 3D surface model over the image is utilized. The 3-D model approach was introduced in 1990 by Hiby & Lovell as a method to photographically capture grey seals regardless of the seals’ orientation, which can otherwise lead to sources of error in photographic studies.

**Errors in Photo-Identification**

In both manual and computer aided photo-identification, misidentification of individuals is a major concern. Misidentification may include, matching two different individuals as the same individual (“false positive”) or failing to match images as the same individual (“false negative”) (Stevick et al., 2001). These two types of errors can alter results differently. False positives (incorrectly matching two different individuals) results in overestimations of survival and recapture rates, and underestimates population size (Hammond, 1986). False negatives (failing to match two photographs of the same individual) results in reduced survival and recapture rates and inflates population estimations. In an effort to reduce errors, only high quality photographs are used, matches are often confirmed by multiple people, catalogues of capture histories are routinely edited, and matching sessions are kept short to avoid the fatigue of photo analysts (Hammondm Mizroch & Donovan, 1990). Finding a method that reduces effort is tremendously important. However, it remains uncertain as to whether manual or computer aided techniques result in fewer photo-identification errors.
Comparing methods in terms of speed and accuracy can be very difficult. Methods have variable steps that make comparisons difficult. Additionally, comparing accuracy through the comparison of error rates between methods is difficult, as estimating error rates can be extremely confusing, and researchers often differ in both their definition of error and reporting of error rates. Errors have been reported various ways including as a number of correct matches found within a specific similarity coefficient threshold (Kelly, 2001), an error rate calculated by the number of incorrect matches over the total number of matching attempts (Morrison et al., 2013), and the number of incorrect possible matches that ranked higher than true matches (Hillman et al., 2003). On occasion, studies also fail to report the total number of images included in the catalogue, which makes interpreting error rates nearly impossible. All in all, reporting of errors found in photo-identification studies is confusing and inconsistent.

In order to switch from a manual to computer aided photographic systems, researchers should be confident that the process is likely to both increase accuracy and speed. In marine mammal research, strides have been made to describe advantages and disadvantaged photo-identification techniques. The largest advancements have occurred in cetacean studies, many of which are now geared to specific species morphological and pigmentation pattern traits, including notches in dolphin dorsal fins and notches as well as patterns in humpback whale flukes (Loughlin et al., 2010). Advancements in cetacean computer aided photographic identification have greatly reduced matching efforts and enhanced the ability to track animals. There has been less focus of photo-identification of pinnipeds due to the difficult nature of manually identifying individuals,
as well as the continued utilization of physical marks and tags. As a result, the applicability of such methods to pinniped studies is far less certain.

**Study Site and Objectives**

Cupsogue Beach County Park, located on the south shore of eastern Long Island, is part of Westhampton Beach (Figure 2). Westhampton beach is a barrier island along the south shore of Long Island, NY, situated between Moriches and Shinnecock Inlet. The barrier island is very vulnerable to beach erosion. Consequently, a number of beach erosion control measures have been implemented under the supervision of the New York Beach Erosion and Hurricane Protection project, including beach nourishment, groin formation and dune construction (Bocamazo et al., 2011). Recreational use of the beach is largely restricted to the summer months. Throughout the seal season (Sept-May) harbor seals are the most abundant pinniped species in the study area. Less frequently observed pinnipeds include grey seals, harp seals and hooded seals. Since monitoring began following the enactment of the Marine Mammal Protection Act (1972), the number of harbor seals in the study area has increased, as have localized strandings of harbor seals in New York and New Jersey (Waring et al., 2010). There are no studies to date that determine if Long Island harbor seals display site fidelity.

The determination of site fidelity as well as other population parameters is extremely important for conservation policy. In the U.S. harbor seals are protected under the Marine Mammal Protection Act (MMPA) (1972). The MMPA prohibits the “take” of marine mammals, which includes the “hunting, killing, capturing or harassing” of marine mammals. Certain exceptions are permitted under Section 101(a) and (b) to allow for the takes associated with scientific research, public display, and incidental
commercial by-catch. The 1994 amendment to the MMPA requires regular stock assessment reports, which include the evaluation of anthropogenic sources of mortality to ensure that takes are below the recommended potential biological removal (PBR).

In U.S. waters, harbor seal takes are below PBR (Waring et al., 2010). The greatest source of anthropogenic mortality is due to fishery by-catch, with the highest mortality seen in juveniles. Herring purse seining, lobster traps, and anchored sink gill net fisheries are the largest contributors to harbor seal by-catch. Fishery by-catch accounts for 20% of the potential biological removal (PBR). While this level of removal is above the 10% mortality goal of the MMPA, mitigation is not deemed to be a priority as the U.S. harbor seal population is increasing (Waring et al., 2010). Further information regarding stock structure is needed to evaluate current, as well as future anthropogenic threats, in particular the effects of ecotourism. The research proposed in this study will aid scientists and managers in tracking individual seals and assessing population trends. Future management should focus on determining the effects of nonlethal disturbance due to local ecotourism, including seal walks and seal cruises that occur throughout the Long Island seal season. Research was conducted under the supervision of a local non-profit research and education group.

The Coastal Research and Education Society of Long Island (CRESLI), founded in 1996, conducts research on cetaceans, pinnipeds, and sea turtles around Long Island. CRESLI’s Seal Research Program helps to monitor seal populations, as well as to conduct long term studies on seal behavior around Long Island. Seal surveys are conducted using land platforms. By compiling these studies, scientists have documented 14 sites around Long Island that seals occupy. Monitoring of these sites as become an
integral part of long term studies. To aid in these studies, in 2009, Arthur H. Kopelman president of CRESLI, began a large-scale photo identification based Capture-Mark-Recapture (CMR) study to identify individual harbor seals hauled out at Cupsogue Beach County Park, based on their natural pelage markings.

The goal of this study through the photographic identification of Long Island harbor seals was to 1) determine if Long Island harbor seals display site fidelity and 2) through the comparison of manual and computer matching photo-identification techniques, determine the applicability of computer matching software to this and other pinniped studies.
Chapter 2 Materials and Methods

Study Site and Data Collection

Harbor seals hauled out on tidally exposed sand bars and swimming in the area of Cupsogue Beach County Park (40°46’ N 72°44’W) were photographed from land during the months of November-April, from November 2010 through April 2014, during seal walks. Disturbances were rare but, when they did occur, they were recorded. Over 20,000 photos of harbor seals have been captured, from land based surveys, using a Nikon D600, which is a full frame camera (Nikon FX forma); Effective pixels = 24.3 million; images were taken in RAW format at 6,016 x 4,016 pixel dimensions. The lens was a Sigma 150-500mm, VR, F5-6.3 lens.

Data Analysis for Manual Photo-identification of Harbor Seals

Photographs were catalogued using Adobe Photoshop. Photographs were given a rating of 0-5, with five being the best quality photos. Criteria for photo quality included resolution and focus, and highly ranked photos were of high resolution and sharp focus. The rate of matching error has been shown to increase substantially with decreasing photo quality; therefore, only photos with a rating of 5 were used for analysis (Stevick et al., 2001).

A scheme to aid in the initial sorting of individuals was adopted based on Crowley, Kelly & Daniel (1999). Each photograph was categorized by: color phase (3 phases), spot to background ratio (5 gradations) and spot complexity (3 gradations). The color phases included, light (light background with dark spots), intermediate, and dark (dark background with light spots) (Figure 3). The spot to background ratio ranged from
1-5, with 1 having the least spot density and 5 having the greatest spot density (Figure 4). Spot complexity included, low, intermediate, and high; with low having the least deviation from the simple oval spot and high characterized by the most deviation from the simple oval spot (Figure 5) (Crowley, Kelly, & Daniel, 1999).

Following the initial sorting, individuals with noticeably distinct marks were flagged. To determine distinctive markings, images were assessed very carefully, beginning with the ventral surface, if available, followed by the neck and head regions. Flagged photos were visually analyzed and either identified as a previously identified individual or a new individual. When appropriate catalogue searches using criteria from the initial sorting were implemented, previously identified individuals were noted, and new individuals were given alphanumeric names designated by the date of capture.

Both previously identified individuals and newly identified individuals were assigned an entry in the photo-id catalogue created using Excel. Information regarding initial classification and sighting history was recorded for each individual. Additionally, each entry was linked to a sheet containing photos of the individual from each capture event and a red square indicating the area that the distinct marking used for identification could be located. Next, photos were carefully inspected in order to ensure that neither “false positives” nor “false negatives” were prevalent in the data set. In order to aid in this process, individuals with markings that closely resembled an object were renamed to reflect this resemblance. Previous names were kept in a column next to the new name in the catalogue to ensure capture histories was not altered. If a false negative or false positive match was found, it was corrected, and the capture histories were updated. Once it was determined that there were no false positives or false negative matches, the number
of seasons for which an individual was captured was recorded. The four seasons were
defined as Nov. 2010- April 2011, Nov. 2011- April 2012, Nov. 2012- April 2013 and
Nov. 2013-April 2014. Additionally, photo records of lesser quality from six seasons
prior to the implementation of a new digital camera in Nov. 2010 were obtained and
analyzed to determine if individuals utilized the same haul-out beyond the scope of the
four year study period.

Finally, for all capture dates the number of seals with unique marks were recorded
as well as the number of seals previously identified. A percentage of seals with good
marks that were already previously identified was determined by the following equation
(# seals with good marks x (1/ID’d seals). The percentages were graphed over time to
determine if photo-identification efforts were improving towards the point at which all
seals with unique marks were identified. In other words was there a positive correlation
between time and percent of seals with unique marks that were identified. Lastly, an
ANOVA statistical test was run to determine if the percentage of seals with good marks,
that were previously identified, differed between years.

Data Analysis for Computer Aided Photo-Identification of Harbor Seals

Photos were run through a computer aided automated matching program initially
developed for grey seals (Hiby & Lovell 1990) (software developed by Conservation
Research Ltd; www.conservationresearch.co.uk). Again, only five star rated photos were
used for analysis. The program is designed to match distinct pelage patterns of seals by
superimposing a 3-dimensional body model over each image and extracting pattern
information (Hiby & Lovell, 1990). Utilizing a three dimensional model image allows
individuals to be identified regardless of the orientation of the animal at the time the photo was taken (Hiby & Lovell, 1990).

Photos were first imported into the new sightings form, including the date the photos were taken. Photos were set for extract of the head and neck region to ensure that, regardless of whether the seal was hauled out or in the water, there would be a fair chance of identifying it. To extract a pattern from an image, points were placed on each subject at the nose and mid flipper. Following the setting of the initial points, “special points” were placed for the “right flipper”, “left flipper”, “left ear”, and “right ear” (Figure 6). Next, the margins of the body were determined by placing points along the upper and lower margins of the body from the pelvis to the neck. An initial fit was created by superimposing a 3D surface model on the image of the seal based upon the placed points (Figure 7). The fit was adjusted to better suit the image as needed, and areas containing features not belonging to the target subject were erased. Once an adequate extract was determined, the pattern cell or identifying array (IA) was extracted and saved for comparison (Figure 8). That pattern cell was displayed in a window containing three images- the first being extracted from the image, the next being the de-trended version of the extract, and the last being the wavelets decomposition of the extract (Figure 9) (Hibey & Lovell, 1990).

Two comparison algorithms, the “n” and “c” algorithms, were used to compare IAs of photographs. The two algorithms were complimentary to one another. The “n” algorithm was most useful in dealing with obscured areas but less useful in dealing with amorphous shapes. The “c” algorithm alternatively, was useful in dealing with amorphous shapes and less useful in dealing with obscured areas. This process resulted
in potential matches being given a similarity coefficient. (Hiby & Lovell, 1990). Images were placed alongside a list of ranked potential matches that needed to be confirmed based on their similarity coefficient (Hibey & Lovell, 1990). Some studies implement the use of similarity coefficient threshold, a defined value of similarity for which potential matches beyond which are not visually inspected. Such a threshold was not implemented in this study, as previously cited thresholds in the literature were based on grey seal analysis. Therefore, all potential matches in the list were visually inspected. Confirmed matches were stored in the library containing a new “matched” ID, along with a column indicating their original ID. Following the visual confirmation stage, the library was inspected for false positives and false negatives. A record of false positive and false negatives was taken, and the false rejection rate (FRR= # false rejections / # identification attempts) and the false positive rate (FPR= # false positives / # identification attempts) was calculated. Matches were identified as, either previous individuals known from the manual identification method, or as new individuals and given a temporary ID. The edited library was used in determining site fidelity. Individual capture histories were inspected to determine how many seasons an individual seals were identified.

**Comparing Manual vs. Computer Aided Photo-Identification**

To compare the effectiveness of computer aided matching against manual identification methods, the sighting frequency of the 177 identified individuals from the manual identification method was graphed alongside the sighting frequencies of those individuals garnered from the computer aided matching software. A t-test was run in order to determine if there was a significant difference between the number of seasons an
individual was identified using the manual and computer aided methods. Additionally, a table was created to determine the number of new individuals sighted each year, as well as the number of individuals re-sighted each year for both manual and computer aided matching methods. Two separate t-tests were conducted to determine if the number of new sightings and the number of re-sightings differed between methods. (# seals with good marks x (1/ID’d seals). The cumulative number of seals identified suing both methods was also compared using a t-test. Finally, the number of cumulative number of seals identified over one, two three and four seasons was compared using a t-test. The comparison was largely limited to comparisons of accuracy, as the steps between methods varied significantly, making time calculations difficult. Previous work on the manual identification of harbor seals had already been initiated before the start of the study, which also made comparing time, as well as error rates, between methods difficult.

**General Population Statistics and Probability of Capture**

In order to identify potential factors that may affect capture probability both within a study season and between seasons a few variables were analyzed. First, an ANOVA was run to determine if change in mean sighting per observation (2011-20114) was significantly different between seasons. This was then expanded to include data from 2007 and another ANOVA was run to determine if change in mean sighting per observation differed between seasons form (2007-2014). Next, in order to determine the effects of study design on the potential amount of individuals that could be captured, the mean number of seals captured was graphed in relation to time that the first photo was taken from low tide. Next, a correlation test was conducted to determine if time from low tide was a significant factor in determining how many seals were captured. Following, a
closer analysis of monthly capture information was analyzed. An ANOVA was run to determine the change in mean sightings per observation between months (averages from 2011-2014). Finally, it was important to determine if males and females differed in their probability of capture. Ten individuals were of known sex. A t-test was used to compare the seasonal sighting frequencies of the known males and females.

**Spatial Analysis of Long Island Harbor Seal Haul-out Sites**

The objective of the spatial analysis was to determine if Long Island Harbor seal haul-out behavior was influenced by the; 1) human population (as a proxy for anthropogenic disturbance); 2) distance to water depths (20m; 30m; 40m; and 50m); and 3) wind speed. Determining what factors influence haul out site selection will aid in the management of local seal populations. The overall goal was display to the haul-out data alongside three rasters displaying, human population, bathymetry and wind speed. An Ordinary Least squares (OLS) was then utilized to determine the relationship between haul-out locations and the environmental variables.

**Blind Study of Manual Matching Success of Harbor Seals**

In order to test the ability of both naïve and trained observers to identify individual seals, methods were adopted based on Patton & Jones (2008) which tested the ability of trained and untrained observers to identify photographs of black rhinos. Four types of identification photographs were chosen, a right and left head view and a right and left flank view. There were 15 individuals in which were at least a right and left flank view and/or a right a left head view i.e. 30 photos. Additional photos of those individuals were added if additional views were available (i.e. if a right flank view was
available as well as a left and right head image view and/or if there were similar but not the same identification photograph from the same perspective). Adding these additional photos brought the total photo count to n=49.

A test was designed using Excel. Each sheet in the excel file corresponded to one matching test. For each perspective (left head, right head, left flank and right flank), there were at least eight individuals that had at least two photos from that perspective, totaling 32 photos. Each image was presented along with the remaining seven in that category and the duplicate match, with given instructions to place a star on the image that represented the correct match. Instructions also indicated that there was a single match for every test. This was done for all four views, totaling in 32 matching tests. Finally, an additional eight tests were compiled including all four views in which matches were randomly selected from previous trials. This brought the total number of tests to n=40.

The Excel file was sent to volunteer participants with various degrees of photo-identification experience. Upon sending their results, volunteers were also asked to provide their age and level of photo-identification experience, if applicable. Participants that indicated they had previous photo-identification were also asked to provide information regarding the duration of their experience and for what species.

Submissions were graded based on the number of correct matches and applicants with photo-identification experience responses were compared against those responses from participants without photo-identification experience. A t-test was used to determine if there was a significant difference between trained and untrained observers. Results were also graphed to assess possible correlations between level of photo-identification experience and manual matching success.
Computer Aided Matching of Grey Seals

In order to determine the efficacy of the computer program to match different species of seals, grey seal photos were obtained from Shoals Marine Lab of seals of grey seal haul-outs on Duck Island, ME (permit # NMFS LOC 16260-01) (Fig.10). In total, 514 photos were imported into the matching software from the 2011 and 2012 field seasons combined. Images were processed in the same manner as harbor seals were in the previous trial. The final catalogue was compared to an ID catalogue provided by Shoals Marine Lab of previously identified seals. Finally, false negative errors and false positive errors were recorded. The false negative rate was defined as the (# of false negative matches/# of potential correct matches). The false positive rate was defined as the (# of false positive matches/# of potential correct matches).

Comparing Error Rates of Harbor Seals and Grey Seals

To compare the false negative rates of harbor seals and grey seals a hypothesis test to determine the difference in proportions was calculated. The null hypothesis was that the false negative rate for harbor seals ≥ the false negative rate for grey seals. The alternative hypothesis was that the false negative rate for harbor seals < the false negative rate of harbor seals. Similarity, to compare the false positive rates of harbor seals and grey seals another hypothesis tests to determine the difference in proportion was calculated. The null hypothesis was that the false positive rate for harbor seals ≥ the false positive rate for grey seals. The alternative hypothesis was that the false negative rate for harbor seals < the false negative rate of harbor seals.
Chapter 3 Results

Manual Photo-Identification of Harbor Seals and Site Fidelity Determination

Results from the manual identification indicate that some individuals display site fidelity, in that they return to the same haul-out location over multiple seasons (Table 1). Eight individuals were observed during all four seasons of the study. Additionally, when data were expanded to include photo-identification work beyond the scope of this study, four individuals were sighted up to eight seasons (Table 2). In total, 202 individuals were noted to have an identifiable marking. Eight were seen over four seasons, four over three seasons, thirteen over two seasons and 177 over a single season. Error rates were difficult to determine, as the photo-identification work began prior to the start of this study and error rates were not previously recorded. Finally, the percentage of seals with unique marks that had been previously identified did not significantly differ between season (p=0.15). There was no correlation between time and percentage of seals with good marks that had been identified (Fig.11).

Computer Aided Photo-Identification of Harbor Seals and Site Fidelity Determination

Computer-Aided results indicated that some individuals display site fidelity. A total of 229 individuals were identified, with nine being observed over four seasons, four noted over three seasons, sixteen seen over two seasons and 200 observed over one season (Table 3).

Both false negatives and false positives identifications occurred using the computer aided method. False negatives occurred when groups of successfully paired individuals failed to match to another group of successfully paired individuals and/or
when a single individual failed to successfully match another individual (Table 4). The False negative rate (# false negative matches/ # of potential matches) was 21.4% (233/1041). The majority of false negatives occurred when images of the same individuals failed to successfully match to one another, resulting in an individual having two or more unique ID’s. False negatives also occurred resulting in individuals having 2-12 unique ID’s. Two individuals, hammerhead and horseshoe, had over 20 unique ID’s as a result of false negative matches. False Positives were far less common than false negatives, with only 6 instances occurring in the sample, corresponding to a false positive error rate (# false positive matches/ # potential matches) of 0.5% (6/1041) (Table 5).

**Comparing Manual vs. Computer Aided Photo-Identification**

In comparing manual and computer aided results it is important to consider both accuracy and speed. Computer aided identification increased accuracy. The number of seasons that an individual was sighted differed significantly between methods, with computer methods on average capturing individuals over more seasons (p=0.037) (Fig. 12). Overall, the computer aided matching schemed resulted in a greater cumulative number of individuals identified although this finding was not significant (p=0.328) (Figure 13). Computer methods also resulted in a greater number of new identifications, which was also not significant (p=0.411) (Table 6). In addition, the computer aided methodology resulted in a greater number of re-sightings across all four years. However, this finding was also not significant (p=0.347) (Fig. 14). In comparing sighting frequency, the manual method of identification, with exception of individuals sighted over three seasons which was equal for both methods, was less than the computer methods but, the difference was not significant (p=0.460) (Fig. 15). There were 10
individuals for which sex could be identified. In all cases, the number of seasons observed for these ten individuals did not differ between manual and computer methods. A t-test indicated that there was not a significant difference between the sex and the number of seasons sighted (p=0.293).

Comparing differences in speed was a much more difficult task, as steps of both methodologies were often too different to quantitatively compare. Where the computer aided method had the greatest potential to decrease effort in the matching phase, this study did not as a similarity coefficient was not invoked to minimize effort in matching. The suggested coefficient proposed by Hiby & Lovell (1990) was not invoked, because the coefficient was determined for grey seals and not largely tested for harbor seals. In addition, accuracy of identification was important in that the study was of greater importance in order to determining whether the population displayed site fidelity and if computer aided methods were reliable method photo-identification.

Photo-identification error rates are also an important comparison to make between methods. While, photo-identification errors were recorded for computer aided methods and to an extent for manual methods a valuable comparison could not be made, because the manual photo-identification had begun prior to the start of this study and previous errors were not accounted for.

**General Population Statistics and Capture Probability**

The mean number of seals per observation differed significantly between seasons within the study period (p=0.01), with 2011 having the greatest observations (>70 individuals) and trending down to 2012-2013 having on average between 40-50
individuals (Fig. 16). However, when mean number of seals per observation was analyzed from 2007-2014 it again was significantly different between years, but the trend was increasing across years (p=0.004) (Fig. 17). An increasing population is consistent with the general increase in population size in the North West stock as a whole (Waring et al., 2007). Time in which the first photo was taken from low tide was not significantly correlated with mean number of seals observed per observation (r=0.03) (Fig. 18). The average number seals observed per month differed significantly, with March having the greatest number of seals observed (p<0.01) (Fig. 19). Sex was not deemed to be a significant factor in determining seasonal sighting frequencies (p=0.7).

Spatial Analysis of LI Harbor Seal Haul-out

Preliminary spatial analysis of the 14 known harbor seal haul out locations around Long Island analyzed the relationship between harbor seal haul-out locations, human population density, bathymetry, and wind speed. The only significant factor in the analysis was human population. There was a significant negative relationship between haul-out sites and human population (p=0.015) (Fig.20). Additionally, the directional distribution of haul-outs showed that haul-out locations were focused in the northeast coast of Long Island (Fig.20). Distance to water depths was not a significant factor in determining haul-out site utilization (20m p=0.17; 30m p=0.06; 40m p=0.25; 50m p=0.14) (Fig.21). However, it should be noted that distance to 30m depth was just shy of being significant (p=0.06). Wind speed was not a significant factor in determining haul-out site utilization (p=0.32) (Fig. 22).
Blind Study Manual Matching Success of Harbor Seals

Ten participants partook in the study, five having no photo-identification experience, and five having varying degrees of photo-identification experience ranging from 3 month internships to 30+ years of experience with photo-identification of harbor seals. T-test results indicated that there was no significant difference between those who had photo-identification experience and those who did not (p=0.7). There was a slight negative relationship between photo-identification experience and percent correct matches (r=-0.1) (Fig. 23). The highest scoring individual did have the most extensive photo-identification experience.

Computer Aided Identification of Grey Seals

Upon comparing the library catalogue to an available photo-identification manual, there were 43 individuals associated with false negative errors. The false negative rate (# false negative matches/ # potential matches) was 17.89% (92/514). 47% of such error were a result of failing to match single photos of individuals to each other. Further, of such errors, 58% were the results of failing to match a photos of a right side of an animal to a photos of a left side of an animal. The remaining false errors occurred from failing to match a group of correctly matched individuals to another group of correctly matched individuals and/or a single photo. In such cases, all errors resulted from failing to match a group of right side photos to a group or single photo of the left side photos or vice versa. The remaining errors occurred from a mix of falsely matched left and right side images (e.g. a group of correctly matched left images and a single left image). There were no cases of false positives in the dataset.
Comparing Error Rates of Harbor and Grey Seals

The hypothesis test to compare difference in proportions of false negative rates between harbor seals and grey seals was not significant (p=0.9), indicating that grey seal false negative errors rates were not greater than harbor seal false negative errors. The hypothesis test to compare differences in proportions of false positives between harbor and grey seals was also not significant (p=0.7), indicating that grey seal false positive error rates were not greater than harbor seal false positive rates.
Chapter 4 Discussion

Site Fidelity of Long Island Harbor Seals

To be able to understanding the dynamics of populations, individuals must be identified over various temporal and spatial scales. Following individual animals allows researchers to determine vital rates, quantify fitness, and understand behavioral patterns (Bolger et al., 2012). Understanding population dynamics is also vitally important from a management perspective, as there are often legal requirements that require marine mammal populations to be monitored and if necessary, given additional protection (Cunningham et al., 2008). Traditionally, pinnipeds have been monitored by physically being captured and placing a visual mark on them. Animals were then monitored via a robust mark-recapture scheme. However, due to the highly invasive nature of these methods, potential risk to both researchers and animals, as well as high cost, such mark-recapture methods have been replaced by photographic mark recapture (PMR) methods based on naturally occurring markings on animals (Bolger et al., 2012). One area in which PMR has been applied to pinniped studies is through the identification of site fidelity.

Site fidelity, defined broadly as the return of an animal to an area previously utilized, has been documented among harbor seals. Seals spend approximately half of their time hauled out on land. Site fidelity in to specific haul-out in response to breeding and foraging behavior has been cited in harbor seals. Harbor seals are coastal animals often remaining within 25km of the coast, providing opportunities to protect important terrestrial haul-outs as well a marine foraging areas (Cunningham et al., 2008). In addition, evidence that seals consistently utilize a network of specific haul-outs
providessupport for the creation of a network of protected areas (Cunningham et al., 208). Also important to consider is the seasonal changes in haul-out behavior, which coincide with life cycle events, including breeding and molting, which may change management needs. Both the manual method of photo-identification, as well as the computer aided method of photo-identification suggests that some harbor seals return over multiple seasons to the same haul-out location in Cupsogue Beach County Park, Long Island, NY. At least 8 seals were observed over the entire study period. While the photo-identification study spanned only four seasons (2011-2014), when new camera equipment greatly enhanced photo-quality, inclusion of photos from 10 seasons indicated that least 4 individuals have returned to Cupsogue Beach County Beach for 8 seasons.

The return of harbor seals to specific haul out locations over multiple years reflects the importance of haul-out behavior and haul out site selection in maintaining overall fitness. Knowledge of what environmental variables drive haul-out site selection and habitat use in marine mammals is an important component in the development of management and conservation strategies (Grigg et al., 2012). Site fidelity in harbor seals has most commonly been associated with specific life history events, including breeding behavior. Many populations of harbor seals display a specific type of site fidelity, termed natal philopatry, in which seals return to their natal site to breed (Kelley et al., 2010). Interestingly, in this study, seals displayed site fidelity in the absence of any major life history events. Harbor seals inhabit coastal areas of Long Island form November- April, just following the molting season and just prior to the breeding season. The absence of any major life history event, indicates that there is some other factor that is driving haul-out site fidelity in this population. Environmental variables which have commonly been
cited as influencing haul out site selection include, access to prey, access to deep water, protection from wind, and distance from relative disturbance (Montgomery, Hoef, & Boveng, 2007). Being able to determine what factors are important in determining haul-out site selection, and site fidelity, will aid in the designation of appropriate management schemes for the population.

Spatial analysis of the 14 known harbor seal haul out locations around Long Island determined that the only significant factor influencing harbor seal haul-out site selection was human population. There was a significant negative relationship between haul-out sites and human population. Additionally, the directional distribution of haul-outs showed that haul-out locations were focused in the northeast coast of Long Island. Distance to water depths and wind speed were not a significant factors in determining haul-out site utilization.

It is common across studies that harbor seals tend to haul-out in aggregations away from human communities (Montgomery et al., 2007). Similar results were found in my project as haul-out locations were negatively related to human population. The spatial distribution of haul-outs indicated that seal haul-outs were focused in the northeast of Long Island. This is consistent with human population trends. Western Long Island is more densely populated than eastern Long Island. I would hypothesize that the north shore was utilized more than the south shore, as the north shore has less wave activity and wave activity has been shown to be negatively correlated with seal haul-out behavior. Access to deep water has been cited as an important factor in haul-out behavior, allowing for quick escape from terrestrial predators and access to prey (Montgomery et al., 2007).
Access to deep water was not a significant factor in determining haul-out site in preliminary spatial analysis. That being said, a more precise measure of distance to water depths would likely improve the strength of the analysis. Manually making polylines was relatively successful in areas where changes in depth were clear and dropped off moderately. However, in areas where water dropped off quickly it was difficult to create accurate polylines without overlap. Additionally, the area off the northeast coast of Long Island, where seal haul-out locations was also an area of deep water. Future work should focus on the bathymetry and prey distribution in this area in relation to haul-out sites.

Harbor seals are central place foragers, tending to remain close to haul-out sites and revisit foraging grounds (Orians & Pearson, 1979; Grigg et al., 2012). Determining if prey availability is an important factor influencing haul-out site selection and subsequent site fidelity is an important prerequisite to management and conservation of the Long Island harbor seal population.

Finally, protection from wind has also been cited as a variable positively affecting seal haul-out behavior. Seals tend to haul-out in areas that are protected from high winds (Watts, 1996). Wind speed was not shown to be a significant factor influencing LI harbor seal haul-outs. This may be due to the fact the data was not ideal for this analysis. The shapefile provided by the National Renewable Energy Laboratory was designed for the site selection of wind turbines. The wind speeds were for 50m height and can therefore only be used relatively to explain haul-out site selection. Additionally, the data had been classified into 5 categories according to ranges of wind speeds. The highest range was given a 5 and deemed the most appropriate site for wind energy while the lowest values were deemed as being poor sites for wind energy. Since the data was
already classified the wind speed was not exact for each haul-out location but was rather an integer from 0-5 representing associated ranges of wind speeds. Having seal level wind speeds would enhance analysis.

Conclusions that can be draw from the data are, that some Long Island harbor seals display site fidelity, in that they return to Cupsogue Beach over multiple seasons. However, this site fidelity is not associated with breeding behavior, as most commonly seen across other populations of harbor seals. In the absence of life history events that dictate haul out behavior, Long Island harbor seals must be influenced by other factors which result in site fidelity. Potential factors may include, distance form disturbance, access to prey and access to deep water. While relatively few seals were seen to return over multiple seasons in relation to seals that were seen over one season, it is possible that more seals could have been identified if survey methods were altered.

Opportunistic survey methods may have limited the amount of seals that could be re-sighted. The number of harbor seals that are hauled out varies considerably over time and between locations. Variability can be partially explained by environmental conditions and life history events (Simpkins et al., 2003; Watts, 1996). Harbor seals tend to haul-out at low tide, although the strength of this correlation varies between sites. Inclement weather can also reduce the amount of seals ashore (Simpkins et al., Watts, 1996). Due to the opportunistic nature of survey methods, coinciding with educational seal walks, identifying and re-sighting individuals was most likely limited. Not all surveys were conducted at low tide when the greatest number of seals would be expected to come ashore.
In addition, haul-out proportions vary seasonally in response to life history events. Haul-out numbers peak in the molting season and pupping season. In the last few weeks of the molting season, as seals are reentering the water haul out numbers can drop by more than 85% (Simpkins et al., 2003; Matthew & Kelley 1996). During the pupping season, females and pups dominate the haul out sites, while males rove nearby waters. This sexual difference in haul-out behavior during the breeding season, likely decreases the re-capture probability for males. Since this study took place outside of the breeding season it is not likely that sexes represented unequal capture probabilities. Of the ten individuals for which sex was determined there was no difference between males and females in the number of seasons sighted. Determining what local conditions that result in the maximum proportion of seals hauled out, would result in the greatest potential for new identifications and re-sightings of individuals.

In terms of seasonality, the best time to conduct a photo-identification study for harbor seals would coincide with the annual molt, and ideal local environmental conditions. Since molting does not occur during the seal season in Long Island, the best approach to increase the accuracy of photo-identification work would be to design a survey around local ideal environmental conditions, within the study season, that result in the greatest number of seals hauled out. These conditions are not well established for Long Island seal populations. Low tide is likely a contributing factor, according to local biologists, but this would need to be further investigated. Photographs collected from 2007-2011 were all taken within 2.5 hours of low tide. Within this times frame there was no correlation between minutes from low tide that the first photograph was taken and overall number of seals captured. Another possibility would be to focus survey efforts at
a certain time within the seal season in which the maximum number of seals are observed. This has not been well established either, but photo-identification data from Dr. Kopleman at Cupsogue spanning 10 seasons indicates that the number of seals observed differed between months. The highest numbers of seals were observed in March. This is logical, considering it takes time for all seals traveling south to reach Long Island. Focusing efforts and funds towards the latter half of the seal season make increase photo-identification efficiency. Further evidence indicating that there is a possibility for greater number of seals to be recaptured, and perhaps indicate that more seals display site fidelity can be seen in the percentage of seals with unique marks that have been previously identified. If all seals with unique marks were being identified, over time the percentages would increase, approaching but never reaching 100% as there is always individuals coming in and out of the population. This trend was not observed in the data. There was no significant relationship between time and the percentage e of seals with unique marks that had been identified. This indicates that there are still individuals that need to be identified, and could perhaps lead to greater re-sighting frequencies. In addition to life history events and environmental conditions, photo-identification errors can also limit the amount of seals that can be captured and accurately identified. In any event, this study indicates that some Long Island harbor seals do display site fidelity.

Sustained patterns of site use have various consequences for management. Showing fidelity to a site increases the risk that a population may experience severe declines due to anthropogenic stress, predation, or disease. While the Northwest stock is increasing, new potential anthropogenic stressors are also increasing. Such stressors
include increases in various eco-tours including seal walks and seal cruises. While the
tours are wonderful opportunities to educate the public, the effects of such tours on seal
populations is largely unknown. Seals have been shown to become more vigilant and
even flush haul-out sites in the presence of ecotourism activities (Granquist &
Sigurjonsdottir, 2014). Increased vigilance and abandonment of haul-out site both
negatively affect overall fitness. What effect this increase in energy expenditure and
reduced fitness has at both the individual and population level is unknown. Harbor seals
populations vary widely in their response to anthropogenic disturbance, with some being
temporally disturbed, some being permanently disturbed, and others habituating to
disturbance. Voluntary management should be put in place to inform guests to remain
calm and for tour operators to remain at an adequate distance as to not disrupt seals.

Other potential threats that are increased when populations show site fidelity to a
small geographic area are those of environmental quality. There is increasing evidence of
mortality due to infectious disease, including morbillivirus. It remains uncertain if
morbillivirus is the cause of epizootics or simply a contributing factor among many
others. Being able to isolate a direct cause, after an animal is stranded can be extremely
difficult. Continued re-infection of populations with diseases that have in the past
contributed to large scale mortality can put additional stresses on populations that are
recovering. Additional environmental stresses include environmental contaminants,
including but not limited to agricultural runoff, PCBs, and organochlorides, as well as
harmful algal blooms and hypoxic events. Long Island is highly urbanized. Spanning
only 13 miles in width, terrestrial activities greatly affect coastal water quality. Coastal
waters of the north-west, where certain harbor seals haul-out are subject to frequent
hypoxic events, due to nutrient input and limited water exchange. Areas on the south shore are more prone to harmful algal blooms as well as both diarrhetic shellfish poisoning (DSP) and paralytic shellfish poisoning (PSP) (Figure 24). Managers should be aware of potential risks to populations and ways in which they may mitigate potential hazards.

Since harbor seal haul-out is based on a multitude of factors and does not solely reflect environmental patchiness, managers must take a precautionary approach when dealing with populations that exhibit site fidelity, to ensure areas that require protection and monitoring are dealt with appropriately (Da Silva & Terhune, 1988). While photo-identification of natural markings has provided a relatively non-invasive approach to monitor populations, careful consideration is required to choose the most appropriate methodology for the study which ideally increases accuracy and reduces cost.

**Comparison of Manual vs. Computer Aided Identification**

The process of photo-identification include three main methods, manual identification, manual identification with alpha-numeric coding, and computer aided matching photo-identification. In choosing the most appropriate method of identification for a scientific study, careful consideration must be taken to acknowledge the advantages and disadvantages of each method to ensure that the most appropriate method is chosen for the particular study and the limitations associated with the resulting study are clearly understood and outlined. Finally, in comparing manual and computer aided methods it is important to consider two key variables-accuracy and speed, in this case qualitatively (Fig. 25).
Manual photo-identification has proven to be both an effective and simple way to approach photo-identification studies, capturing many individuals in diverse conditions both cost effectively and reliably. Such methods have been successfully utilized to categorize small photographic libraries, but once a catalogue becomes larger and/or involves more complex pattern recognition, manual identification becomes very tedious. Even so, manual methods continue to be utilized to manage large databases. It is often the case that such databases began long before the application of computer assisted identification, and the pre-processing of such large quantities of photos for proper use in photo-identification software is too time consuming and often viewed as not worth the effort. Manual methods are also sensitive to reductions in photo quality, with successful matches decreasing and error rates increasing as photo quality decreases. Similarly, the less distinct the individuals marking, the more errors will occur. This case study indicated that manual photo-identification can be successfully utilized for large databases of seals with unique pelage markings, to track individuals over multiple years. Compared to computer assisted methods, the manual method resulted in fewer identifications of seals and lower sighting frequencies, making this method slightly less accurate. It was also lengthy and tedious work. Nevertheless, the method was easy to apply and resulted in little confusion or technical difficulty. One additional requirement of many manual photo-identification methods, and one that was applied in this case study, is the use of alpha numeric coding.

The use of alphanumeric coding within manual identification practices expedites the process of matching individuals, particularly for larger catalogues. Alphanumeric coding is appropriate when marks can be consistently categorized and are stable over
time. This method requires additional time in the pre-processing of photos. Such
drawbacks should be considered when assessing the applicability of using alpha numeric
coding. Keywords can also be used to categorize individuals and aid in the matching
process. In this case study, animals that displayed unique marks and were determined to
not have been previously identified were given alpha numeric codes corresponding to the
date they were captured and categorized based on color phase, distinctiveness of marks
and spot density. This categorization aided in initiating searches for potential matches
and well as confirming suspected matches

Finally, computer assisted matching software, which can be broken down into
metric and nonmetric systems, although more technically challenging is often the most
appropriate and choice when dealing with large and complex catalogues. While, not all
comparisons were significant in this study, computer aided matching software did
significantly increase the re-sighting of individuals, which suggests increased efficiency.
I would predict that with even larger photographic catalogues that this benefit would be
more pronounced. Costs are low, as many programs are available for free. However,
pre-processing of photos is often a lengthy a process. Photos are first imported and set
for pattern extraction for metric systems or unique classification in nonmetric systems.
These steps are often tedious and more time consuming when compared to manual
methods. Next, designed algorithms determine a list of potential matches, and visual
confirmation is conducted by the researcher. This step has the capability to greatly
reduce matching time, if accurate matches can consistently be found in the potential
match list, thus avoiding false negative errors and reducing the amount of photos the
image has to be compared to. This process can be ever more beneficial if a similarity
coefficient can be determined and invoked in which individuals in the list that exceed such a value are not visually checked (Auger-Méthé, Marcoux, & Whitehead, 2011). For example, Hiby and Lovell (1990) found that 98% of true grey seals matches occurred when similarity coefficients were greater than 0.5. Implementing the use the threshold greatly reduced matching efforts, and the authors further suggested that those utilizing their computer assisted matching software to identify grey seals apply a similar threshold value to their methodologies. A threshold was not invoked in the present study, because the target species was the harbor seal. Harbor seals display unique pelage markings in way of spots or rings that vary greatly from grey seal pelages. Therefore, the entire list of potential matches was searched during the visual confirmation stage, which minimized the potential benefits, in terms of reduced effort; that could be realized with the use of a computer aided matching system. This balance between time and reduction in false negatives is apparent across photo-identification studies. As protocols are implemented to reduce false negative errors, such as inspecting the entire list of potential matches and/or having more than once individual visually confirm a match, false negative errors are often reduced. However, this cautionary approach leads to greater effort and more time required. Finding a balance between these diverging needs of accuracy and timeliness is often difficult and is largely based on the study and researchers’ discretion. In this case study, the use of computer assisted photo-identification resulted in a greater number of identifiable individuals and higher re-sighting frequencies, despite having a lengthy pre-processing phase and visual confirmation stage (Table 6). Many photo-identifications studies will err on the side of caution and implement methodologies that aim to reduce the rate of error, as errors can significantly alter results.
Errors in Photo-Identification

Photo-identification errors are common in both manual and computer aided methods. Two possible sources of error in photo-identification work are false positive errors, identifying two different individuals as the same individual, a false negative errors, identifying two photos of the same individual as different- a false negative (Patton & Jones, 2008).

False positive errors can cause large biases in population parameter estimations. However, risk aversion to false positives increases the probability of a false negative finding, the balance between which has not been widely investigated. The likelihood of a false positive result is dependent upon the similarity of markings, with highly similar markings causing the greatest risk for false positive errors. In general, false positive errors are of little concern in photo-identification studies, as strict matching protocols, including the use of restrictive criteria, minimize the risk of false positive error.

Additionally, final visual confirmation is normally conducted by experienced photo-analysts and/or by two individuals (Stevick et al., 2001). A limited number of false positive errors was detected in the present study (Table 5). False positives that did occur can most likely be attributed to human error, as matching images is time consuming as well as physically and mentally exhausting.

A much greater concern in photo-identification studies is the risk of false negative errors. False negative errors have been shown to be common in photo-identification studies utilizing natural marking (Stevick et al., 2001). False negative errors means that a single individual is identified as two individuals. False negative errors were very prevalent in the present study, resulting in a false negative rate of 21.4 % (Table 4).
Both photo quality and the distinctiveness of marks appear to be related to error rates. In both errors related to photo quality and distinctiveness of marks, important assumptions for mark-recapture studies are violated (Hammond, 1986). If marks are indistinct the probability of identifying that animal is decreased, leading to heterogeneity of the sampling probabilities. Photographic quality is independent of the animal it represents. However, it is difficult to consider photo quality and the distinctiveness of marks independently. Stevick et al. (2001) determined that coders often gave photos of lower quality a lower score for distinctiveness of marks. Stevick et al. (2001) found no error rates with the highest quality photos, but high levels of error with each successive decline in photo quality measure. Pattern change can also result in error. Errors related to distinctiveness of marks increases when images are only partial photographs, i.e. photos that do not show all of the area of focus are subject to high rates of error.

Errors can significantly alter results. Both false negatives and false positive errors can be reduced by controlling for photo-quality and setting high photo quality standards. That being said, eliminating low quality photos can substantially reduce sample sizes and result in loss of precision. Additionally, very distinctive individuals can often be manually identified in even in photos of low quality. Being able to determine error rates specific to image quality and distinctiveness allows researchers to make corrections for biases resulting from false positive and false negative identifications (Stevick et al., 2001). Double marking experiments, which compare results from mark-recapture utilizing physical tags and genetic analysis, are conducted to estimate the rate of error. However, double matching experiments have not widely been applied to studies utilizing natural markings and genetic analysis. (Stevick et al., 2001)
Manual Matching of Trained vs. Untrained Photo-analysts

There was no significant difference in manual matching success in relation to photo-identification experience (p>0.05). However, the sample size for this study was very small, which makes meaningful comparisons difficult. Ideally, there would be more participants with clear categorizes of relative photo-identification experience, depending on the amount of time, species involved and age. The highest percentage of correct matches was achieved by an individual with 30+ years of photo-identification, including work with harbor seals, which may indicate that many years of experience is beneficial. However, such gains were not seen in individuals with less experience, such as a few months during an internship. In addition, some individuals with no experience at all scored high, indicating that some people may simply be better at visual identification than others. These findings are consistent with the literature. Schofield et al., (2008) tested the ability of trained, and untrained observers to identify sea turtles. They found that while all participants scored highly the most experienced had the highest scores. A follow up study implemented a 20 min training protocol to inform untrained observers of what to look for in identifying turtles. The study demonstrated that there was significant improvement among untrained observes following the short training protocol (Schofield et al., 2008). Implementing a similar approach in further tests to determine the ability of untrained observers to identify harbor seals would be beneficial.

Comparing Error Rates of Harbor and Grey Seals

Matching grey seal photos using the computer software was slightly more effective, resulting in less photo-identification errors, than matching harbor seals photos. Grey seals have more distinctive markings, of contrasting dark and light patches, which
likely made them easier to identify. The computer software was also developed specifically for grey seals, and perhaps when tailored to meet the needs of harbor seals could perform equally as well in identifying harbor seals. The most errors were false negative errors. Future research efforts should focus on reducing false negative errors.

Citizen Science Applications

There is a growing desire for public participation in scientific research termed “Citizen Science” (Bonney et al., 2009). Projects that foster community involvement in scientific research highlight the benefits that can be garnered from such collaboration for both the public and scientists. Citizen science projects promote public involvement in scientific research and environmental education, addressing the broader need to for open dialogue between the scientific community and the public to foster stewardship of our environment. A previously restrictive field, science has been hesitant to incorporate the public into scientific research, in fear that public observers are not reliable. However, as Bonney et al. (2009) pointed out, with clear protocol, data collection forms, and interactive public support networks, citizen science can provide reliable observer data to contribute to scientific research of unprecedented scope. Photo-identification in many respects is a prime candidate for a citizen science project.

Public volunteers could potentially be involved in the photo collection, importing of photos to a computer assisted program, pre-processing of photos, and even the visual confirmation of individuals. Collaborative databases can be created worldwide by both public participants and scientists alike to upload images to an internet based photo-identification library. For example, a system that incorporates images of manta rays by novice divers is being created (Town, Marshall & Sethasathien, 2013). This process,
however, should be done with caution, as to not promote novice photographers getting too close to seals, and potentially disturbing them. Education is key, and by including the public in the photo-identification monitoring, more will be educated. Photo-identification provides a valuable opportunity to involve the local community in monitoring of populations, by integrating the local involvement through the uploading of images to the photo-identification library, thus giving the community a larger role in the management of local marine mammal populations (Auger-Méthé, Marcouz & Whitehead et al., 2011). Arguably, such integration of the community into scientific project should lead to greater respect and understanding of their local environment. The user friendly interface of computer assisted matching software provides further opportunities for public participation in scientific research. Volunteers can also aid in the visual confirmation of individuals, but there are concerns regarding observer reliability when using the public in citizen science projects.

Matching individuals is the most time consuming process of any photo-identification study, and thus provides the greatest potential benefit for implementing public participation. However, there is a concern than visual confirmation, traditionally done by at least one trained photo analysts, can be done effectively and reliably by an untrained observer. As with any photo-identification project false negative and false positive errors are of great concern as they can substantially alter results.

The computer matching software is easy to operate and could easily be incorporated into a citizen science project (Auger-Méthé, Marcoux & Whitehead, 2011). Much of the work can be accomplished given a training of the software and requires little familiarity with the individual seals. The visual confirmation phase would likely require
a more experienced photo-analyst make the final confirmation, unless untrained observers are at least given a training session and demonstrate accuracy and reliability in their identifications.

**Future Research Needs**

While shown to be more accurate, computer aided matching software techniques are still tedious and time consuming. Automated pre-processing is necessary to further increase the speed of computer assisted programs (Town et al., 2013). Additionally, it has been noticed that combining a metric and nonmetric based computer aided system to identify sperm whales has improved accuracy (Beekmans et al., 2005). Utilizing metric and non-metric systems alongside each other may be beneficial in pinniped studies. Metric systems can be used to extract patterns and non-metric systems to describe mark complexity, color phase, and spot density. Finally, to increase the speed of matching individuals a threshold should be found in which potential matches beyond a similarity coefficient are not checked. This would require further harbor seal photo-identification tests in the software recording where in the list of potential matches true matches occurred.

**Study Limitations**

The study was able to determine that some Long Island seals display site fidelity and that the computer aided photo-identification methods were slightly more accurate, in that individuals were re-sighted more frequently using the computer method than manual photo-identification methods. While differences were not always statistically significant, as catalogue sizes grow and more seals are identified these differences will likely be more pronounced. One area in which the comparison of method was weak, was in determining
photo-identification errors. Since the manual photo-identification process was already begun before the start of the study it was not possible to account for photo-identification errors made prior to the start of the study. The study was also weak in its ability to compare methods based on speed. Methods varied tremendously, and again since manual photo-identification had already begun prior to this study comparisons were difficult. Matching individuals is the most time consuming portion of photo-identification. Without the use of a similarity coefficient threshold, matching using the computer software was not reduced. Further research in harbor seal photo-identification and the development of specific harbor seal similarity coefficient threshold, will lead to tremendous gains in this technology. Particularly considering that harbor seals are the most widespread pinniped species. Finally, continued surveys should be conducted to determine if photo-identification experiences significantly alters manual matching success.
Chapter 5 Conclusion

This study indicates that photo-identification based mark recapture using natural markings is an effective method to study pinniped population dynamics. This study also determined that some individual harbor seals return to Cupsogue Beach County Park over multiple seasons, displaying site fidelity. Continued monitoring is necessary to ensure that these areas are adequately protected. In addition, it was determined that while both manual and computer aided photo-identification methods were effective at managing large photograph catalogues of harbor seals, computer methods were slightly more accurate resulting in a greater number of identifiable seals and higher numbers of re-sightings. That being said, both methods were very tedious and timely. Automating pre-processing steps as well as developing and implementing a similarity coefficient threshold specific to harbor seals will likely increase the speed of visual matching and make computer aided photo-identification more desirable. Such thresholds have been successfully implemented in grey seal photo-identification. Finally, the use of photo-identification and particularly CRESLIs’ work in Long Island lends itself to citizen science. Volunteers can aid in data collection, processing and matching of photographs. CRESLI as an organization that prides itself on engaging the local community and as a result often utilizes scientific data collection trips as an opportunity for public education. Seal walks and whale watches provide opportunities for Dr. Kopelman to collect photographic information and educate the public. Furthering the public involvement through a citizen science framework would likely greatly enhance the long term study of the local seal population as well as increase awareness, education and stewardship of the local environment. Advancements in computer aided matching software will certainly
increase the applicability of such methods to pinniped studies, allowing for the study of population parameters and conservation of species through the monitoring of large, long term databases effectively and accurate
Figure 1. Coastal range of western Atlantic harbor seal. Long Island harbor seals are seasonal inhabitants, occupying NY coastal waters from September-May. Data from NOAA, protected species.
Figure 2. Map of Long Island harbor seal haul-out locations indicating the location of the study site, Cupsogue Beach County Park, outlined by a yellow square.
Figure 3. Example of manual matching color phase criteria. Individual seals were determined to have color phases that were
Figure 4. Example of manual matching spot density criteria, with one having the least spots and 5 having the most spots.
Figure 5. Example of manual matching spot complexity criteria. Individuals were determined to have low, intermediate and high spot complexity. Low complexity individuals had spots which did not deviate from an oval spot and high complexity individuals had many spots which were variable and were more complex than oval spots.
Figure 6. Example of computer aided pre-processing of images by placing points corresponding to different anatomical locations on the image. First, points were placed on the nose and mid-flipper. Next points were placed indicating the location of the right flipper, left flipper, right eye and left eye when appropriate. Finally, the margins of the body were determined by placing red points along the top of the body and blue points along the bottom of the body.
Figure 7. Example of computer matching pre-processing in which a 3D surface model is superimposed on the image.
Figure 8: Example of computer aided pre-processing in which an extract is taken from the image.
Figure 9: Example of computer aided pre-processing in which extracts are saved. Image displays from left the extract, detrended extract, and wavelet view of the extract.
Figure 10. Photo of grey seal indicating the distinctive pelage markings of contrasting dark and lite coloration
Figure 11. The (number of seals with good marks x (1/ID’d seals)) was constant. If all seals with unique marks were previously identified than the percentage would be 100%.
Figure 12. Manual vs. computer aided photo-identification sighting frequencies of known individuals. The x-axis displays names of individuals and the y-axis shows the number of seasons sighted. Blue bars represent manual identifications and orange bars represent computer aided identifications. Methods differed significantly $p=0.0373$. Computer methods had greater overall re-sightings.
Figure 13. Cumulative number of seals identified over four seasons using manual and computer aided methods. Manual identification results are displayed in blue and computed aided results are displayed in orange. Both methods showed an increase in number of identified seals over the four seasons. Computer methods consistently resulted in greater number of identifications although this was not significant (p=0.328)
Figure 14. Manual vs Computer aided resightings data. The number of individuals which were determined to be resighted using manual methods are displayed in blue and the number of individuals determined to be resighted using computer aided methods are displayed in orange. The computer aided matching method resulted in greater number of individuals having repeat sightings but, this result was not significant.
Figure 15. Manual vs. computer aided seasonal sighting frequencies. The number of individuals sighted using manual identification (blue) and computer aided identification (orange) over one, two three and four seasons. While computer methods resulted in larger sighting frequencies over 1, 3, and 4 seasons the difference was not significant (p=0.460).
Figure 16. Change in mean sighting per observation within study period differed significantly between years ($p=0.01$). There was a decrease trend across years in the number of seals observed per sighting.
Figure 17. Change in mean seal sighting per observation (2007-2014) differed significantly between years (p=0.004). The trend in mean observations was increasing,
Figure 18. Number of harbor seals observed within minutes of low tide. All photos were taken within 2.5 hours of low tide. Within this time frame there was no correlation between the number of seals identified and the minutes from low tide.
Figure 19. Monthly mean number of harbor seals observed (2004-2014) p<0.01
Figure 20. Long Island, NY harbor seal haul-out locations and human population. The top map displays human population density including NYC and the bottom map displays human population density excluding NYC. The bottom image is a more accurate representation of Long Island population density trends, with the west being more densely populated than the east. Mean haul-out is indicated by a red star, median haul-out by a yellow circle, and directional distribution by the opaque oval. Harbor seal haul-out was negatively related to human population density (0.015)
Figure 21: Bathymetry and Harbor Seal Haul. Distance from haul-out to water depth was not a significant in determining haul-out site. (20m p=0.17; 30m p=0.06; 40m p=0.25; 50m p=0.14)
Figure 22. Wind Speed at 50m and Haul-out Site Locations. Wind speed was not significantly related to haul-out locations (p=0.32).
Effect of Photo-identification Experience on Manual Matching Success

Figure 23. Effects of Photo-identification experience on manual matching success. There was no significant difference between those with and without experience (p>0.05)
Figure 24. Long Island water quality issues
Figure 25. Comparing manual and computer aided methods in terms of accuracy and speed.
Table 1. Manual sighting frequency of individuals within study period (Nov. 2010 Apr.14)

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<th># of individuals re-sighted</th>
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Table 2. Manual sightings frequency of seals within 10 seasons (Nov.2004- Apr. 2014)

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Table 3: Computer aided sighting frequency of individuals within study period (Nov. 2010-Apr. 2014)

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Table 4: Computer aided identification of harbor seals false negative errors

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|               | 26  | 207 | 233 |
Table 5. Computer aided identification of harbor seals false positive errors

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Table 6. Manual vs. computer aided new Identifications and re-sighting. Although new identifications and re-sightings were greater for computer methodologies. These results were not statistically significant (p=0.411; p=0.347)

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<th>Re-sightings (Manual)</th>
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Table 7. Computer aided identification of grey seals false negative errors

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