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Effects of rearing methods on survival of released free-ranging juvenile southern sea otters

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ABSTRACT

Since 1984, Monterey Bay Aquarium's Sea Otter Research and Conservation (SORAC) program has treated more than 70 stranded newborn sea otter pups. Pups rehabilitated for release have been reared by methods that rely heavily on human care, contributing to release failures. From 1986 to 2000, sixty-seven percent (67%) of unsuccessful pup releases resulted from failures to reintegrate with the wild population and avoid interactions with humans. To address these failures, SORAC initiated a sea otter surrogate program, pairing stranded pups with captive adult females that adopt pups as their own. We predicted that pups reared by surrogate females ($n = 5$, 2001–2002) would develop foraging skills at a younger age, and would have greater success re-acclimating to the wild compared with pups rehabilitated by traditional methods ($n = 6$, 1998–2000). Results indicated that surrogate-reared pups began foraging independently on live-prey 2–3 weeks earlier, and had greater survival rates (71% vs. 31%) in the wild than pups reared without surrogates. The surrogate program, therefore, was less labor-intensive and more effective than traditional rehabilitation methods. In addition to these practical advantages, the surrogate program may also benefit research and conservation objectives for southern sea otters by providing means to (1) better understand pup behavioral and physiological development, (2) measure energetic costs of rearing pups to indicate why survival rate of prime-aged females is declining, (3) improve techniques to reintroduce sea otters in the event of a catastrophic decline in the wild population, and (4) engage and educate the public regarding threats to sea otters and their near-shore marine environment.

1. Introduction

Wildlife rehabilitation is a natural consequence of increasing contact between humans and nature, a relationship of special significance when managing threatened or endangered species (Fitzgerald, 1994). Traditionally, rehabilitation has focused on treating and releasing injured or ill individual animals, with limited resources to devote to research regarding success after release or its effects on the wild population (Bennet, 1992; Ben-David et al., 2002; Lander and Gulland, 2003; Lunney et al., 2004). The current trend when managing threatened or endangered species, however, has been to expand these goals to not only develop expertise essential to humanely treat individuals, but also gather information critical to ensure species survival, such as understanding disease processes contributing to mortality (Gulland, 1999; Kelly and Sleeman, 2003; Greig et al., 2005; Colegrove et al., 2005), improving monitoring and reintroduction strategies (Saltz, 1998; Biggins et al., 1998, 1999; Vargas and Anderson, 1999; Beck et al., 2002; Stoinski et al., 2003), and educating the

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public to promote stewardship of habitats critical to wildlife (USFWS, 2003). In this sense, wildlife rehabilitation is an essential conservation tool for populations vulnerable to catastrophic decline.

The future of the southern sea otter *Enhydra lutris nereis* population is uncertain primarily due to its limited range, extending 300 miles from Half Moon Bay to Point Conception along the California coastline, its vulnerability to a catastrophic oil spill, and its slow recovery from commercial exploitation (USFWS, 2003). The southern sea otter (pop. 2735; USGS, 2005) is currently listed as "Threatened" under the US Endangered Species Act of 1973 as amended (16 United States Code, pp. 1531–1543 [Suppl. IV 1974]). In response to this threatened status, the United States Fish and Wildlife Service (USFWS) published the Final Revised Recovery Plan for the Southern Sea Otter (USFWS, 2003), which identifies actions necessary for protection and recovery. Recovery actions include population monitoring, assessment and elimination of fisheries-related incidental deaths, evaluation of delisting thresholds for the population, and improvement of captive management techniques, including rehabilitation and reintroduction of stranded or oiled otters, to mitigate effects of a catastrophic oil spill if such an event occurs (USFWS, 2003). The Sea Otter Research and Conservation (SORAC) program at the Monterey Bay Aquarium (MBA) has focused on this latter action by refining techniques to release stranded sea otters to the wild after medical treatment and rehabilitation in captivity.

Since 1984, SORAC's rehabilitation program has treated more than 70 newborn sea otter pups (i.e., <8 weeks old) that have stranded throughout the southern sea otter range along the central California coastline (Figs. 1 and 2). Pups stranded due to premature separation from their mothers, possibly resulting from mother's death, poor health, inexperience, or her inadvertent loss of a pup during stormy seas. These pups generally washed ashore within hours of separation from their mothers with no discernable injuries or defects; therefore, after treatment for dehydration and hypothermia, their rate of survival in captivity throughout rehabilitation was high (87%, MBA SORAC, unpublished data). Despite this high survival rate, these pups demonstrated a significantly lower rate of success re-acclimating to the wild as juveniles (27% survival per year, MBA SORAC, unpublished data) when compared with annual survival estimates for wild juveniles (80–88%, Siniff and Ralls, 1991; 75%, Hanni, 2003).

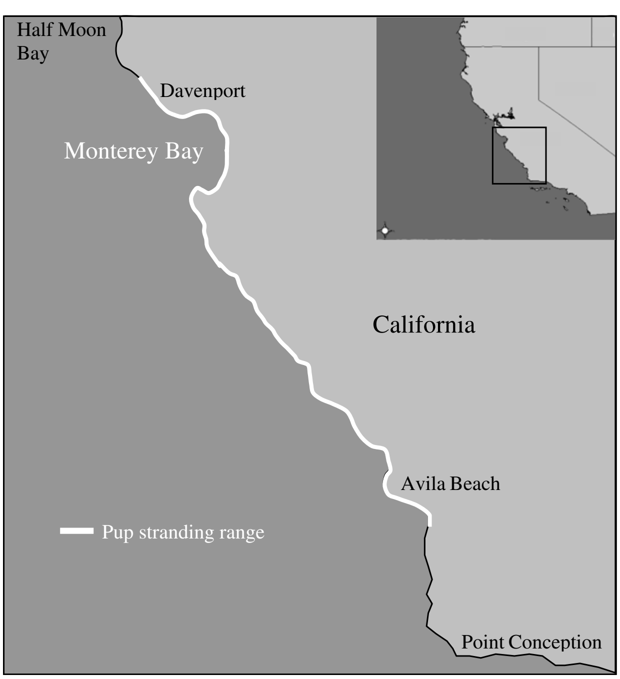

Fig. 1 – Southern sea otter range, and pup stranding range.

As newborns, pups are completely dependent on their mothers for survival. During a four- to nine-month dependency (Riedman et al., 1994), pups gradually mature and develop the physical characteristics, skills, and experience necessary to survive on their own in the wild. To compensate for the absence of a wild sea otter mother during this lengthy dependency, pups rehabilitated for release have been raised by methods that relied heavily on human care, a factor that may have contributed to release failures and low survival in the wild. From 1986 to 2000, 67% of unsuccessful releases resulted from the failure of pups to reintegrate with the wild population and avoid interactions with humans (MBA SORAC, unpublished data). These individuals were recaptured and permanently placed in captivity.

To address these failures, SORAC initiated a surrogate program, pairing stranded pups with non-releasable adult female sea otters that adopt the pups as their own (Fig. 3). During 2001, two females stranded ashore along the central California coastline, exhibiting signs of illness or injury; and after treatment, observation, and consultation with USFWS, behavior or medical concerns prevented their release to the wild. Because each demonstrated maternal behavior while in captivity, we investigated their use as surrogates for rearing stranded newborn pups. Although the time interval necessary for each surrogate to accept and bond with a pup varied from a single introduction to several during the course of a week, neither surrogate rejected a pup. In contrast with other strategies, the surrogate provides species-specific mentoring and tactile stimulation while grooming and nurturing the pup. The surrogate also provides nourishment through food sharing and demonstrates feeding methods, such as dismembering crabs and cracking open hard-shelled bivalves using rocks as tools.

Surrogacy has been implemented opportunistically and successfully, in a variety of settings, by a handful of zoos, aquaria, and wildlife management agencies to rear orphaned young in captivity (*Tursiops truncatus*, Ridgway et al., 1995; *Steno bredanensis*, Gaspar and Lenzi, 2000; *Gorilla gorilla*, Hoff et al., 2005) and in the wild (*Ursus americanus*, Rogers, 1985), or accelerate breeding in a threatened marsupial (*Petrogale penicillata*, Taggart et al., 2005; Schultz et al., 2006). Among terrestrial and marine mammals, this is the first case in which captive female surrogates have been used to rear wild-born orphans for return to the wild.

The purpose of this study was to compare the effectiveness of the surrogate program with traditional methods that relied primarily on human care. We predicted that surrogates would provide a social environment that stimulates natural behavior and facilitates learning among young sea otters. Sur-

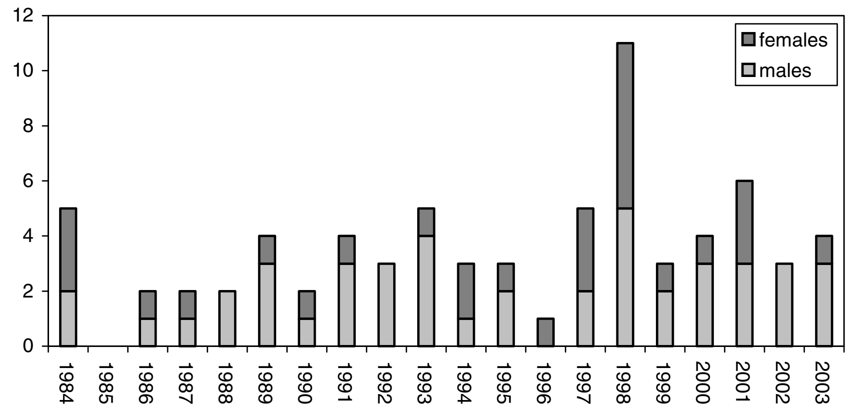

Fig. 2 – Newborn sea otter pup (<8 weeks) strandings since 1984.

rogate-reared pups, therefore, should develop foraging skills at a younger age than pups reared by traditional methods. In addition, we predicted that this social environment would override potentially detrimental effects of captivity and close contact with humans. As a result, after release as juveniles, these otters would avoid interactions with humans, exhibit greater success readapting to life in the wild when compared with non-surrogate-reared pups, and demonstrate survival in the wild at a rate comparable to free-ranging juveniles. These improvements in rehabilitation of newborn sea otters may be relevant to sea otter recovery in the event of a catastrophic population decline.

2. Materials and methods

To test our predictions, we compared behavior development during captive rehabilitation, release success, and known survival in the wild of surrogate-reared male pups ($n = 5$, 2001–2003) with non-surrogate reared male pups ($n = 6$, 1998–2000). For a broader comparison of survival, we also included survival rates in the wild of all newborn male pups raised for release from 1986 to 1998 ($n = 20$), survival rates of free-ranging juvenile males observed during a recent field study ($n = 12$, Hanni, 2003), and survival rates in the wild of surrogate-reared male pups from 2004 ($n = 2$). Since fall 2001, when the surrogate program was implemented, the majority of stranded newborn pups have been male (88%), so only male pups were rehabilitated using the surrogate method during this study period from 2001 to 2003. All comparisons among surrogate reared, non-surrogate reared, and wild-reared pups, excluded females to avoid bias in sample selection. Since 1984 male and female pups have stranded with similar frequency. The prevalence in male pup strandings during this study period, therefore, is most likely the result of chance and does not reflect a greater probability that male pups strand.

Six non-surrogate-reared pups were raised alone in a nursery or other managed environment with an extensive haul-out or dry area and an adjacent pool. Human caregivers provided grooming and feeding on a 24-h basis. As the pups matured and demonstrated basic foraging and grooming skills, they were moved to a larger tank environment, with one or two cohort(s) if available, to continue their rehabilitation with minimal close contact with humans. Four of these six pups also spent several hours per week in the ocean with a human free-diver to provide opportunities to explore their native habitat, and develop skills to find live-prey and socialize with wild otters.

Five surrogate-reared pups were gradually introduced to and housed with a surrogate mother throughout their rehabilitation (Fig. 3). The interval from stranding to pairing with a surrogate was dependent on two conditions: the pup's ability to obtain sufficient nourishment on its own or from the surrogate, and the surrogate's acceptance of the pup as demonstrated by her maternal behavior, such as sharing food, grooming, and resting with the pup. Until these conditions were met, newborn pups received treatment similar to pups rehabilitated by traditional methods relying on human care. Two of these five pups were separated from their surrogates for several hours a week to spend time in the ocean, exploring their native habitat with a human free-diver.

Behavior development was measured by determining the age when each pup demonstrated a targeted behavioral milestone relevant to foraging-skill development. Milestones included (1) pounding objects together on their chest, (2) foraging on (diving, searching, retrieving, eating) partially prepared/cracked open live-prey (mussels, clams, crabs), (3)

Fig. 3 – Pup with a surrogate.

biting open whole live mussels, (4) pounding open whole live clams, and (5) successfully feeding on live crabs (variety of methods). These behaviors were compared with developmental milestones of wild sea otter pups (Payne and Jameson, 1984).

Before release, pups were instrumented with surgically implanted VHF radio transmitters (Advanced Telemetry; Ralls et al., 1989) and color-coded flipper tags. During the first month after release, daily resights were undertaken from shore; after this period, resights were made semi-weekly. Trackers conducted resights using VHF radio receiver and a handheld directional 3-element Yagi antenna. Surveys for missing otters were conducted throughout their central coast range by using a fixed-wing aircraft equipped with radio receivers. Effort and methods of tracking were similar for surrogate and non-surrogate reared pups.

We determined release success by whether or not the released juvenile (1) demonstrated proficient foraging on its own in the wild and (2) avoided contact with humans after release. Because sea otters unable to forage sufficiently in the wild invariably died or required recapture within two weeks, individuals that survived a month and longer, without contact with humans, were considered successful. Juveniles that exhibited foraging skills, but demonstrated a tendency to interact with humans after release, were regarded as a mixed outcome. Often these individuals underwent relocations to remote areas of the southern sea otter range; and if undesirable interactions persisted, threatening the sea otter or public safety, the otter was eventually removed from the wild. A release was considered unsuccessful if the juvenile failed to forage successfully and required recapture, or if it disappeared before recapture without demonstrating skills necessary to survive in the wild.

To measure or compare the effects of rehabilitation strategies on behavior development and release success, we calculated the time pups spent in each rehabilitation setting from age 8 to 24 weeks. Rehabilitation settings included (1) "nursery" tank with a human caregiver, (2) larger outdoor tank with a female sea otter surrogate, (3) outdoor tank alone, (4) ocean with a free-diver, or (5) outdoor tank with cohorts. We then used canonical correlation to determine how these rehabilitation strategies affected pups' foraging-skill development, comparing time in different rehabilitation settings with the age at which pups demonstrated targeted foraging skills, such as biting open mussels, pounding open clams, and foraging on live crabs. In addition, we specifically evaluated behavior development of surrogate and non-surrogate-reared pups by performing a *t*-test, comparing the mean ages when surrogate and non-surrogate-reared pups demonstrated each foraging skill.

Finally, we performed factor analysis and compared factor scores using ANOVA (Kruskal–Wallis test) and multiple contrasts (Kruskal–Wallis *H* statistic) to investigate whether rehabilitation strategy was related to release outcome, and if so, to determine how each method contributed to release success or failure. We then compared known survival in the wild of surrogate-reared ($n = 7$, 2001–2004) and non-surrogate pups ($n = 6$, 1998–2000; $n = 20$, 1987–2000) with wild-reared pups ($n = 12$; Hanni, 2003) using chi-square analysis and Dennett multiple comparison test.

3. Results

By comparing time pups spent in each rehabilitation setting from age 8 to 24 weeks ($n = 11$), three primary rehabilitation strategies were apparent: pups reared by surrogates, pups raised with cohorts, and pups reared in relative isolation (Table 1). Pups reared by surrogates or with cohorts were introduced to their surrogate or cohort(s) at a relatively young age, 7.3 weeks (SE 1.4, *R* 2.0–10.0) and 8.5 weeks (SE 1.0, *R* 6.0–11.0), respectively, and spent more of their time in rehabilitation housed with these otters (60–80%), compared with pups reared in relative isolation. Pups raised primarily in isolation were introduced to other otters much later in their rehabilitation (18 weeks of age) and spent 80% of their time alone during rehabilitation. These pups, however, spent the most time overall and significantly more time than surrogate-reared pups, exploring the ocean with a human free-diver. Only two pups each from the surrogate and cohort rehabilitation strategies also spent consistent time throughout their rehabilitation exploring the ocean, so overall time in the ocean among these strategies was comparably low (Table 1).

Using canonical analyses, foraging skill development and rehabilitation method were significantly correlated (*canonical* $r = 0.88$, $\chi^2 = 13.5$, $p = 0.035$, Fig. 4). A surrogate-rearing setting was the only strategy that significantly contributed (factor structure coefficient $r = 0.86$) to early development of foraging skills, which included biting open mussels (factor structure coefficient $r = 0.98$) and eating live-crab (factor structure coefficient $r = 0.73$), while housing a pup in an outdoor tank alone or in isolation was most related (factor structure coefficient $r = 0.89$) to a slower demonstration of these skills. In contrast, time spent with cohorts had no measurable effect (factor structure coefficient $r = 0.08$) on behavior development when compared with other methods. All other rehabilitation settings, such as nursery with a human caregiver, ocean swims with a free-diver, and outdoor tank with a single cohort, were significantly negatively correlated with early development of skills. Pounding open clams was positively correlated with biting open mussels, so rehabilitation methods had a similar effect on the development of this milestone. Surrogate-reared pups, therefore, developed all foraging skills at a significantly younger age (by 2–3 weeks) than non-surrogate-reared pups and an age similar to their wild counterparts (Table 2).

Release outcome was also related to rehabilitation setting (Kruskal–Wallis test, $H = 8.6$, $p < 0.002$, Fig. 5), and post hoc multiple contrasts indicated that successful pups were reared in significantly different settings than pups with failed and mixed release outcomes ($H = 2.6$, $p < 0.02$). Surrogate-rearing was the only factor that significantly contributed (factor loading, Pearson correlation $r = 0.91$) to release success, and rearing in an outdoor tank alone contributed most (factor loading, Pearson correlation $r = 0.83$) to release failure. Again, in this model, time spent with cohorts had little effect (factor loading, Pearson correlation $r = 0.12$) on release outcome, and all other rehabilitation settings, including ocean swims, were negatively correlated with surrogacy and did not contribute significantly to release success.

All surrogate-reared pups had successful releases as juveniles. These juveniles demonstrated the skills necessary to

Table 1 – Rehabilitation summary

Rehabilitation strategy (*n*)	Mean age (wks) ± SE when pup introduced to surrogate or cohort	Mean % time ± SE with surrogate, cohort, or alone	Mean ocean time ± SE (h/wk)
Surrogate-reared (5)	7.3 ± 1.4	81% ± 6 (w/surrogate)	1.0 ± 0.5
Cohort-reared (4)	8.5 ± 1.0	60% ± 10 (w/ cohort)	4.9 ± 3.2
Lone-reared (2)	18 ± 0.5	80 % ± 4 (alone)	6.4 ± 0.5

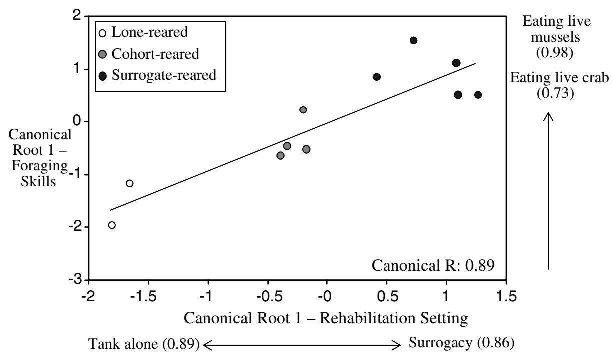

Fig. 4 – Canonical correlation comparing rehabilitation strategy (surrogate-reared, cohort-reared, lone reared) and foraging skill development (eating live mussels and crab) among individual pups. Significant variables and their factor structure coefficients (Pearson correlation *r*) are listed.

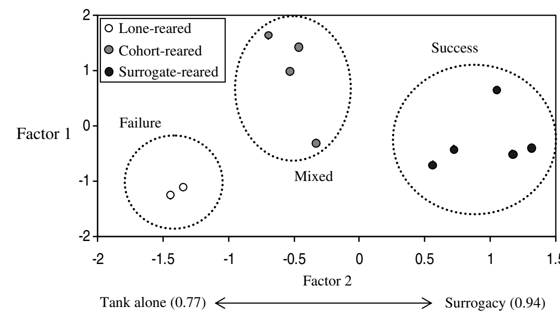

Fig. 5 – Factor analysis comparing rehabilitation strategy and release outcome (failure, mixed, success) among individual pups. Significant variables and their factor loadings (Pearson correlation *r*) are listed.

survive in the wild, avoided interactions with humans, and required no relocations. By contrast, all pups raised with cohorts had mixed release outcomes as juveniles, demonstrating skills necessary to survive in the wild but interacting with people after release. Three of four of these juveniles (75%) required relocation to remote areas within central California, one of which was eventually recaptured and permanently placed in captivity. Neither pup reared in isolation demonstrated skills necessary to survive in the wild. One was recaptured and permanently placed in captivity; the other disappeared after fewer than 24 h in the wild and within hours of a planned recapture.

Finally, known survival of surrogate-reared juveniles in the wild to one year (71%) was comparable to survival of free-ranging juveniles (75%; Hanni, 2003). By contrast, survival of non-surrogate-reared juveniles in the wild to one year (31%) was significantly less than survival of their wild cohorts ($\chi^2 = 8.09$, $p < 0.05$; Dennett test $q_{\text{wild-surrogate}} = 0.403$, $p > 0.05$, Dennett test $q_{\text{wild-nonsurrogate}} = 5.04$, $p < 0.05$; Table 3).

4. Discussion and conclusions

Although newly implemented by SORAC, the surrogate program is proving to be an effective method for rehabilitating and releasing sea otters that strand as newborns. Stranded pups reared by this method demonstrated skills necessary to forage successfully, reintegrate with the wild population, and avoid interactions with humans after release, a significant contrast to behavior of newborn pups reared by methods that rely primarily on human care. In a captive setting, close contact with humans can have detrimental effects on competence, survival, and reproduction after release by disrupting social development or filial and sexual imprinting, which occurs as young learn appropriate or natural social behaviors and identify peers (Bateson, 1966, 1978; Carlstead, 1996). Surrogacy addresses these well-known challenges of rehabilitation by providing a social environment that stimulates natural behavior and facilitates learning, essentially overriding detrimental effects from contact with humans in captivity; so after release, surrogate-reared sea otter pups readapted to living in the wild.

Table 2 – t-Test comparison of foraging skill development or mean age ± SE when surrogate-reared and non-surrogate-reared pups demonstrated behavior milestones, with reference to wild-reared pup development

Milestone	Mean age (wks) ± SE of surrogate-reared pups	Mean age (wks) ± SE of non-surrogate-reared pups	*t*-Value	*p*-Value	Age (wks) of wild pups[a]
Foraging on cracked live prey	8.4 ± 0.7	11.2 ± 0.6	4.1	0.04	8–10
Pounding objects together on chest	9.5 ± 1.0	11.2 ± 0.4	2.4	0.003	9.5
Biting open mussels	12.3 ± 0.4	14.5 ± 0.5	4.3	0.002	14–20
Pounding open live clams	13.9 ± 1.0	16.5 ± 0.8	2.7	0.02	14–20
Foraging on live crabs	19.2 ± 0.7	21.8 ± 0.3	4.3	0.002	20–24

a Payne and Jameson (1984).

Table 3 – Post-release survival rate in the wild (in months) among non-surrogate reared, surrogate-reared, and free-ranging juvenile male otters

Interval in the wild	Non-surrogate reared (%) $n = 26$	Surrogate-reared (%) $n = 7$	Free-ranging (%) $n = 12$[a]
0–1 month	**58**	**100**	100
1–6 months	80	71	83
6–12 months	67	100	90
Overall	**31**	71	**75**

a Hanni (2003)

Before implementing the surrogate program, SORAC's primary rehabilitation strategy was an ocean swim program, which focused on providing pups with exposure to their natural marine environment and opportunities to interact and socialize directly with wild sea otters while accompanying a human free-diver. Behavioral training for release or direct contact with a release area is a strategy common among reintroduction programs to enhance post-release survival (Box, 1991; Biggins et al., 1998, 1999; Beck et al., 2002). Our results indicated, however, that ocean swims had no discernible positive effect on behavior development or release success when compared with surrogacy. Even in the absence of a surrogate, ocean swims did not increase the probability that pups would forage successfully in the wild. Furthermore, regular close contact with a human free-diver, when combined with unavoidable exposure to human caregivers during rearing, decreased their probability of survival in the wild. These pups were more likely to interact with humans after release, which often required their recapture and permanent placement in captivity to ensure their safety and avoid potential injury to the public. When combined with surrogacy, pups receiving ocean swims demonstrated no difference in release outcome when compared with non-swim surrogate-reared pups that returned to the wild. By eliminating ocean swims but continuing to provide environmentally enriched captive conditions that simulate native habitat—such as feedings of live rock crabs, clams, and mussels—these surrogate-reared pups learned to recognize and forage on prey available in the wild independently from ocean swims with a human free-diver.

Another rehabilitation strategy commonly implemented by SORAC involved pairing or grouping pups with other socially compatible sea otters undergoing rehabilitation, usually older pups and juveniles, which was thought to provide exposure to a social environment more natural than a setting consisting only of human caregivers. This method has proven especially effective in rehabilitation of pinniped pups (The Marine Mammal Center (TMMC), 2005), such as harbor and elephant seals, in which maternal investment consists of a short but intense period of lactation, and sea lions, which experience a greater duration of maternal investment, but whose young are extremely gregarious, precocious, and spend the majority of their developmental period with other pups while their mothers are at sea (Riedman, 1990). By contrast, interactions between sea otter pups reared in the wild may occur prior to weaning, but these interactions are usually brief, primarily social in nature, and secondary to contact with their mother. Rearing sea otter pups with cohorts, therefore, did not significantly improve release outcome when compared with surrogacy, presumably because these socially and developmentally naïve companions could neither nurture nor demonstrate skills similar to a maternal adult sea otter. In addition, this strategy was dependent upon the unpredictable temporal and demographic nature of otter strandings, so a few pups, while waiting for a suitable companion, were reared in relative isolation, which proved detrimental to their release success or ability to readapt to conditions in the wild.

Although surrogacy had been discussed for years by program staff as a desirable alternative to rehabilitation methods relying on human caregivers, this method was not considered possible until two suitable prime-age females that stranded in 2001 remained healthy in a captive environment but failed to meet criteria for release to the wild. Adoption and alloparenting (i.e., demonstration of maternal behavior toward another's young) has been observed in a wild southern sea otter (Staedler and Riedman, 1989) and a variety of other marine mammals, such as captive bottlenose dolphins (Caldwell and Caldwell, 1966; Smolders, 1988; Ridgway et al., 1995), and wild harbor seals (Schaeff et al., 1999). Among marine mammals, maternal investment in young is high, and survival of young depends upon the experience of the mother. Adoption behavior, therefore, may provide a young female with experience necessary to, at some point in the future, increase survival of her own offspring (Gaspar et al., 2000). For this reason, surrogacy using captive adult females, which can be provided with unlimited food resources while rearing a stranded newborn, is a viable rehabilitation strategy.

Rehabilitation of newborn sea otter pups by SORAC's traditional methods required long hours of human care and resulted in a low probability of survival in the wild after release. By contrast, surrogacy is less labor-intensive and significantly more effective. In addition to these practical advantages, the early success of the surrogate program may be relevant to captive sea otter management and other population recovery actions, including research and public education. For example, rearing stranded newborns in a controlled environment with surrogate females can provide a means to research pup behavioral and physiological development and to measure the energetic costs of rearing pups, which may indicate why survival rates of prime-aged females in the wild are declining—a condition that is strongly implicated in the slow recovery of the population (Estes et al., 2003; Tinker et al., 2004). Continuing to research and refine this rehabilitation strategy may increase the knowledge and experience necessary to successfully reintroduce sea otters in the event of a catastrophic decline in the wild population. SORAC is monitoring surrogate-reared pups in the wild to determine their long-term survival rates and quantify their potential reproductive contribution to the wild population.

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REFERENCES

Bateson, P.P.G., 1966. The characteristics and context of imprinting. Biological Review 41, 177–220.

Bateson, P.P.G., 1978. Early experience and sexual preference. In: Hutchinson, J.B. (Ed.), Biological Determinants of Behaviour. Wiley, London, pp. 29–53.

Beck, B.B., Castro, M.I., Stoinski, T.S., Ballou, J., 2002. The effects of pre-release environments on survivorship in reintroduced golden lion tamarins. In: Kleiman, D.G., Rylands, A. (Eds.), The Lion Tamarins of Brazil: Twenty-five Years of Research and Conservation. Smithsonian Institution Press, Washington, DC, pp. 283–300.

Ben-David, M., Blundell, G.M., Blake, J.E., 2002. Post-release survival of river otters: effects of exposure to crude oil and captivity. Journal of Wildlife Management 66, 1208–1223.

Bennet, J., 1992. A glut of gibbons is Sarawak is rehabilitation the answer? Oryx 26, 157–164.

Biggins, D.E., Godbey, J.L., Hanebury, L.R., Luce, B., Marinari, P.E., Matchett, M.R., Vargas, A., 1998. The effect of rearing methods on survival of reintroduced black-footed ferrets. Journal of Wildlife Management 62, 643–653.

Biggins, D.E., Vargas, A., Godbey, J.L., Anderson, S.H., 1999. Influence of prerelease experience on reintroduced black-footed ferrets (*Mustela nigripes*). Biological Conservation 89, 121–129.

Box, H.O., 1991. Training for life after release: simian primates as examples. Symposium of the Zoological Society London 62, 111–123.

Carlstead, K., 1996. Effects of captivity on behavior. In: Kleiman, D.G., Allen, M.E., Thompson, K.V., Lumpkin, S., Harris, H. (Eds.), Wild Mammals in Captivity. University of Chicago Press, Chicago, pp. 317–333.

Caldwell, M.C., Caldwell, D.K., 1966. Epimeletic (care-giving) behavior in Cetacea. In: Norris, K.S. (Ed.), Whales, Dolphins, and Porpoises. University of California Press, Los Angeles, California, pp. 755–789.

Colegrove, K.M., Greig, D.J., Gulland, F.M.D., 2005. Causes of live stranding of northern elephant seals (*Mirounga angustirostris*) and pacific harbor seals (*Phoca vitulina*) along the central California coast, 1992–2001. Aquatic Mammals 31, 1–10.

Estes, J.A., Hatfield, B.B., Ralls, K., Ames, J., 2003. Causes of mortality in California sea otters during periods of population growth and decline. Marine Mammal Science 19, 198–216.

Fitzgerald, G., 1994. Wildlife rehabilitation and the need for a professional intervention. Medecin Veterinaire du Quebec, 31–33. Special Issue.

Gaspar, C., Lenzi, R., Reddy, M.L., Sweeney, J., 2000. Spontaneous lactation by an adult *Tursiops truncates* in response to a stranded *Steno bredanensis* calf. Marine Mammal Science 16, 653–658.

Greig, D.J., Gulland, F.M.D., Kreuder, C., 2005. A decade of live California sea lion (*Zalophus californianus*) strandings along the central California coast: causes and trends, 1991–2000. Aquatic Mammals 31, 11–22.

Gulland, F.M., 1999. Stranded seals: important sentinels. Journal of the American Veterinary Medical Association 214, 1191–1192.

Hanni, K.D., 2003. Survival of juvenile rehabilitated and free-ranging southern sea otters, *Enhydra lutris nereis*, PhD thesis, UCD.

Hoff, M.P., Tarou, L.R., Horton, C., Mayo, L., Maple, T.L., 2005. Notes on the introduction of an 11 week-old infant Western lowland gorilla *Gorilla gorilla gorilla* to a non-lactating surrogate mother at Zoo Atlanta. Annales Academiae Regiae Scientiarum Upsaliensis 39, 191–198.

Kelly, T.R., Sleeman, J.M., 2003. Morbidity and mortality of red foxes (Vulpes vulpes) and gray foxes (Urocyon cinereoargenteus) admitted to the Wildlife Center of Virginia, 1993–2001. Journal of Wildlife Diseases 39, 467–469.

Lander, M.E., Gulland, F.M.D., 2003. Rehabilitation and post-release monitoring of Stellar sea lion pups raised in captivity. Wildlife Society Bulletin 31, 1047–1053.

Lunney, D., Gresser, S.M., Mahon, P.S., Matthews, A., 2004. Post-fire survival and reproduction of rehabilitated and unburnt koalas. Biological Conservation 120, 567–575.

Payne, S.F., Jameson, R.J., 1984. Early behavioral development of the sea otter, *Enhydra lutris*. Journal of Mammalogy 65, 527–531.

Ralls, K., Williams, T.W., Siniff, D.B., Kuechle, V.B., 1989. An intraperitoneal radio transmitter for sea otters. Marine Mammal Science 5, 376–381.

Ridgway, S., Kamolnick, T., Reddy, M., Curry, C., 1995. Orphan-induced lactation in Tursiops and analysis of collected milk. Marine Mammal Science 11, 172–182.

Riedman, M.L., 1990. The Pinnipeds: Seals, Sea lions, and Walruses. University of California Press, Berkley.

Riedman, M.L., Estes, J.A., Staedler, M.M., Giles, A.A., Carlson, D.R., 1994. Breeding patterns and reproductive success of California sea otters. Journal of Wildlife Management 58, 391–399.

Rogers, L.L., 1985. Aiding the wild survival of orphaned bear cubs. Wildlife Rehabilitation 4, 104–111.

Saltz, D., 1998. A long-term systematic approach to planning reintroductions: the Persian fallow deer and the Arabian oryx in Israel. Animal Conservation 1, 245–252.

Schaeff, C.M., Boness, D.J., Bowen, W.D., 1999. Female distribution, genetic relatedness, and fostering behavior in harbour seals, *Phoca vitulina*. Animal Behaviour 57, 427–434.

Schultz, D.J., Whitehead, P.J., Taggart, D.A., 2006. Review of surrogacy program for endangered Victorian brush-tailed rock wallaby (*Petrogale penicillata*) with special reference to animal husbandry and veterinary considerations. Journal of Zoo and Wildlife Medicine 37, 33–39.

Siniff, D.B., Ralls, K., 1991. Reproduction, survival and tag loss in California sea otters. Marine Mammal Science 7, 211–229.

Smolders, J., 1988. Adoption behavior in the bottlenose dolphin. Aquatic Mammals 14, 78–81.

Staedler, M.M., Riedman, M.L., 1989. A case of adoption in the California sea otter. Marine Mammal Science 5, 391–394.

Stoinski, T.S., Beck, B.B., Bloomsmith, M.A., Maple, T.L., 2003. A behavioral comparison of captive-born, reintroduced golden lion tamarins and their wild-born offspring. Behaviour 140, 137–160.

Taggart, D.A., Schultz, D., White, C., Whitehead, P., Underwood, G., Phillips, K., 2005. Cross-fostering, growth and reproductive studies in the brush-tailed rock-wallaby, *Petrogale penicillata* (Marsupialia:Macropodidae): efforts to accelerate breeding in a threatened marsupial species. Australian Journal of Zoology 53, 313–323.

The Marine Mammal Center (TMMC), 2005. www.marinemammalcenter.org/what_we_do/rehab/current_patients.asp.

Tinker, M.T, Doak, D.F., Estes, J.A., Hatfield, B.B, Staedler, M.M, Bodkin, J.L., 2004. Spatial and temporal variation in the demography of southern sea otters. In: Tinker, M.T., Estes, J.A, Ralls, K., Williams, T.M., Jessup, D., Costa, D.P. (Eds.), Population Dynamics and Biology of the California Sea Otter

(*Enhydra lutris nereis*) at the Southern End of its Range. A Report Prepared for the Minerals Management Service (Task # 17605), Final Draft, October 2004.

US Fish and Wildlife Service (USFWS), 2003. Final Revised Recovery Plan for the Southern Sea Otter (*Enhydra lutris nereis*). Portland, Oregon.

United States Geological Survey (USGS), Western Ecological Research Center (WERC), 2005. www.werc.usgs.gov/otters/ca-surveydata.html.

Vargas, A., Anderson, S.H., 1999. Effects of experience and cage enrichment on predatory skills of black-footed ferrets (*Mustela nigripes*). Journal of Mammalogy 80, 263–269.