Landscape Assessment of Habitat and Population Recovery of Common Loons (*Gavia immer*) in Massachusetts, USA

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Abstract.—Common Loons (*Gavia immer*) recolonized Massachusetts in 1975 from a single breeding pair on the Quabbin Reservoir. Since then, the population has grown to 33 pairs that occupy 14 lakes, but the full recovery potential of the population is unknown. This study analyzed population data and habitat suitability, as well as compared population dynamics, of the Common Loon population in Massachusetts to the Common Loon population in New Hampshire to determine if a recovery similar to the one seen in New Hampshire is possible. Results indicated that a large-scale recovery may be possible as enough suitable habitat exists to support about 300 pairs statewide. Current population stresses have not led to a decline; thus, management efforts can be increased to encourage further growth. Due to a small initial population, some aspects of a small population paradigm and an allee affect may have contributed to the slow population growth since 1975 as compared to Vermont and New Hampshire.

Key words.—carrying capacity, Common Loon, *Gavia immer*, Massachusetts, recovery.

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The Common Loon (*Gavia immer*) is a remarkable inhabitant of North America's northern lakes that experienced dramatic declines and subsequent recoveries in the southern part of its range. For example, Massachusetts' Common Loon population was extirpated from 1872 until 1975, when a single nesting pair was discovered on the Quabbin Reservoir (Bent 1919; Clark 1975). Steady growth since then has resulted in an estimate of 33 pairs on 14 lakes, mostly in the north-central part of the State (McAlice 2010, 2011). While the Massachusetts Department of Conservation and Recreation and the Massachusetts Division of Fisheries and Wildlife monitor and manage the Common Loons on these lakes, little is known about presence in the rest of the State.

The decline of Common Loons (loons) in Massachusetts was largely due to habitat loss and sport shooting (McIntyre 1988; Evers 2007). Loon conservation efforts began in 1975 in response to the dramatic declines witnessed in many southern populations. Subsequent population recoveries have often been aided by the use of nest rafts (Evers 2007). These floating platforms minimize threats (e.g., fluctuating water levels, shoreline predation, and disturbance) to nesting success (Piper 2002; DeSorbo *et al.* 2007; Vogel and Cooley 2010). Nesting exclosures, created by ropes and signs, have also been a viable management tool to discourage human disturbance.

Growth of the Massachusetts loon population to date has been impressive. Evidence suggests further population expansion is possible (Evers 2007; McAlice 2010). A large number of lakes exist in the State, many of which likely possess habitat characteristics conducive to nesting loons and lie along north-to-south loon presence distributions (Evers 2007; Kuhn-Hines 2008). To date, management of the Massachusetts population has focused on providing nesting rafts. While this has been effective, effort could be increased. Additionally, unofficial sightings of loons across the State are reported each year, suggesting other lakes may be attracting territorial pairs and the population may be larger than reported.

The objective of this study was to quantitatively and qualitatively assess the recovery potential of the Massachusetts loon population. This was achieved through a multi-step process, including aggregating and analyzing Massachusetts population data for demographic trends, comparing those trends to New Hampshire trends, and estimating carrying capacity. The aggregation of these techniques creates an approach useful in assessing overall health and growth potential for loon populations, or any waterbird populations with similar available data, that may have conservation uncertainties.

METHODS

Population data for the Massachusetts Common Loon population during 1975-2011 was gathered from a variety of sources, including the Massachusetts Department of Conservation and Recreation monitoring reports, Massachusetts Division of Fisheries and Wildlife monitoring reports, the Biodiversity Research Institute database of loon population data, and loon necropsy reports for Massachusetts from the Tufts University Wildlife Center. These data consisted of records of territorial pairs (TP), nesting pairs (NP), successful nesting pairs (SNP), chicks hatched (CH), and chicks surviving (CS) within each breeding season.

Surveys were conducted statewide in 2011 to determine the full extent of loon presence in Massachusetts. High priority lakes were identified using loon sightings from eBird (eBird 2010), as well as available lake data on surface area (> 16 ha) and depth (> 6 m). Loon presence or absence and any evidence of productivity were recorded following the Loon Preservation Committee survey methods (Loon Preservation Committee 2004). Lakes with water access were surveyed by kayak, and all other lakes were surveyed from shore. Survey durations varied depending upon survey type, lake size, and lake shape with the aim of detecting loon presence. Lakes with observed loon presence were revisited at least once to confirm continued presence.

Demographic data were analyzed by year, lake, and territory. The focus was to detect trends in TP, NP, SNP, CH, and CS, as well as the following rates: nesting propensity (NP/TP), successful nests (SNP/TP), nesting success (CH/NP), chick survivorship (CS/CH), and overall productivity (CS/TP). Source lakes (CS/TP: $\bar{x} > 0.48$) and sink lakes (CS/TP: $\bar{x} < 0.48$), as well as source years and sink years, were identified (Evers 2007; Grear *et al.* 2009). Overall productivity (CS/TP) and length of time occupied was compared for each lake and territory to determine possible site fidelity, habitat quality, and trends in colonization of lakes over time. These demographic analyses established what lakes loons occupied over time, where growth and expansion occurred in the State, and to what degree each lake contributed to productivity.

The number of exclosures created, nest rafts deployed, nest rafts used by pairs, and chicks hatched from nesting rafts were compiled for 1986-2011. To determine the effectiveness of rafts in Massachusetts, nesting success (CH/NP) of raft nesting pairs was compared to natural nesting pairs for 1986-2011 using a Mann-Whitney test (Minitab, Inc. 2010).

A carrying capacity (K) for Massachusetts was roughly estimated by determining lake suitability using known thresholds for lake surface area (ha), maximum depth (m), and total phosphorus (µg/L) which is directly related to water clarity and can be considered a proxy for secchi depth (Kuhn-Hines 2008). The minimum viable surface area was established as 5 ha, maximum viable phosphorous concentrations were 0.031 µg/L, and lakes could not be < 10 m depth with phosphorus concentrations > 0.020 µg/L or > 10 m depth with phosphorus concentrations > 0.030 µg/L (Kuhn-Hines 2008). Likelihood of dispersal and colonization to distant or less suitable areas of the State was also factored into the estimate. Based on observed occupancy in New Hampshire, lakes 24-49 ha were determined to be possibly capable of hosting one pair, lakes 50-123 ha were determined to be capable of hosting one pair, lakes 124+ ha were determined to be capable of hosting more than one pair, and lakes < 24 ha were determined to likely be part of a multi-lake territory (Vogel *et al.* 2009; Vogel and Cooley 2010). For lakes smaller than 50 ha, pairs were assigned fractionally following trends in New Hampshire. For the 24-49 ha size class, a pair count of 0.65 was assigned to each lake representing the 65% occupancy of this size class in New Hampshire. For lakes < 24 ha, their total area was divided by 50 to account for minimum territory size and then multiplied by 0.5 to represent 50% occupancy in New Hampshire. Lakes 124+ ha were manually assigned loon pairs based on expected occupancy considering lake size, lake shape, shoreline complexity, presence of islands, and shoreline development. In total, 885 lakes were included in the carrying capacity estimate.

Population trends, demographic rates, carrying capacity, and management efforts were identified and compared to those of the New Hampshire population. Demographic data and management efforts were compared to New Hampshire from 1983-2011 using Wilcoxon Signed-Ranks tests (Minitab, Inc. 2010).

RESULTS

During the 2011 statewide survey, 146 lakes were surveyed. Eight lakes (6%) were found to have some degree of previously undocumented loon presence. One territorial pair was found on Stodge Meadow Pond in Worcester County. Residents of the lake reported the presence of a pair since the early 1980s. Other loon presence included single loons on Crocker Pond, Asnacomet Pond, and Hickory Hills Lake in central Massachusetts; Lake Garfield, Pelham Lake, and Plainfield Pond/Windsor Reservoir in western Massachusetts; and Haggetts Pond in the northeastern part of the State. Unofficial reports of loon presence included one to two single adults in the southeastern part of the State on Silver Lake and Lake Pearl, and a successful breeding pair on Noyes Pond in Berkshire County in 2009, but absent in 2010 and 2011.

The Massachusetts Common Loon population grew from a single pair in 1975 to 33 pairs in 2012. Yearly productivity has varied

over time, but has averaged 0.54 CS/TP (SD = 0.26) since 1983. Productivity was high during the 1980s through 1997, but has since declined for all lakes including Quabbin and Wachusett Reservoirs (Fig. 1). In the past decade, productivity has often fallen below the 0.48 CS/TP needed for population stability (Fig. 2) (Evers 2007; Grear *et al.* 2009). Since 1983, nesting propensity has averaged 0.71 (SD = 0.15) with an average nest success rate of 0.67 (SD = 0.23), which has led to an average chicks hatched per nesting pair of 0.97 (SD = 0.34) and chick survivorship of 0.86 (SD = 0.24). As a result, the rate of chicks surviving per nesting pair has been high (0.80, SD = 0.31); however, this may have been inflated by inconsistent monitoring.

Of the 28 lakes with known loon presence, 18 (64%) had at least one pair (33 total pairs), with the Quabbin and Wachusett Reservoirs hosting 17 and five pairs, respectively. Only four lakes had ≥ 0.48 average productivity (CS/TP) since 1983: Wachusett Reservoir (five pairs), Bickford Reservoir, Fitchburg Reservoir, Paradise Pond, and Springfield (Ludlow) Reservoir. Although hosting 17 pairs, Quabbin Reservoir only had an average CS/TP of 0.43, a value largely driven by a few highly successful territories. Productivity of recently colonized lakes was highly variable; however, longer occupied lakes showed a statistically significant positive relationship with productivity (t = 3.61, P = 0.001, n = 17, r^2 = 0.053). Quabbin Reservoir remained at five pairs or less until the mid-1990s and then steadily increased. During this period, Wachusett Reservoir increased to four pairs and a fifth pair was discovered in 2011 (Fig. 2). There was a significant positive relationship between the length of time a territory was occupied and productivity (t = 4.13, P = 0.001, n = 42, r^2 = 0.080).

The deployment of nest rafts began in 1986 with one raft and grew to 13 rafts in 2011. However, nesting exclosures (ropes

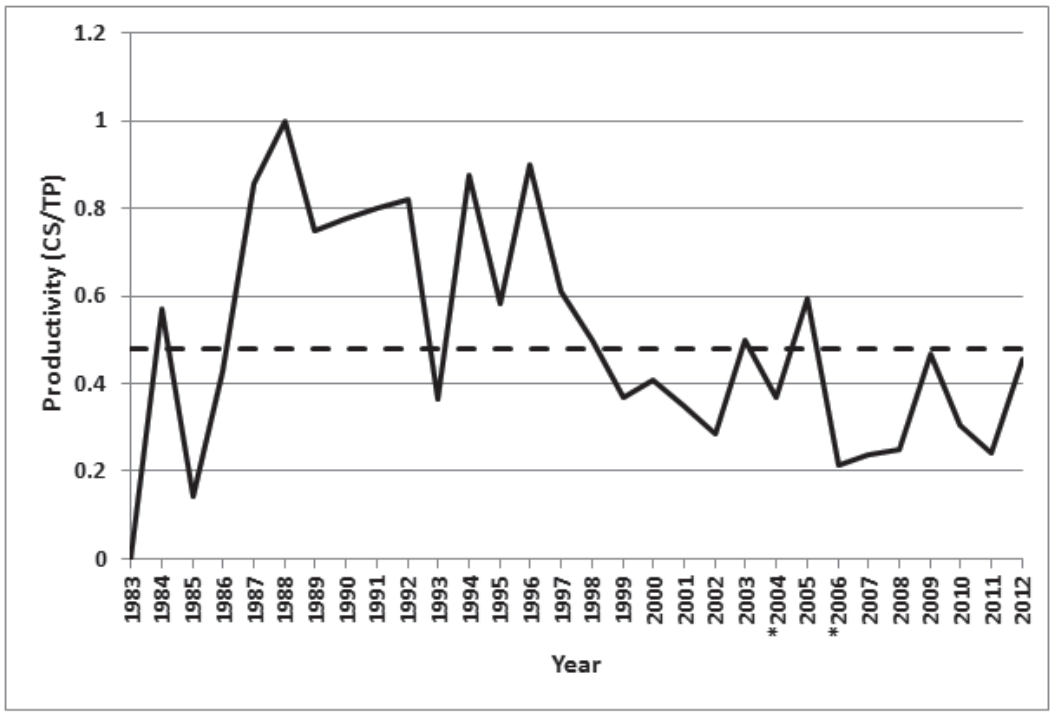

Figure 1. Productivity of Common Loons in Massachusetts, 1983-2011 (indicated by the solid line). The dashed line indicates the estimated 0.48 productivity (chicks surviving (CS)/territorial pairs (TP)) threshold for population stability. No monitoring was done on non-Massachusetts Department of Conservation and Recreation lakes in 2004 and 2006.

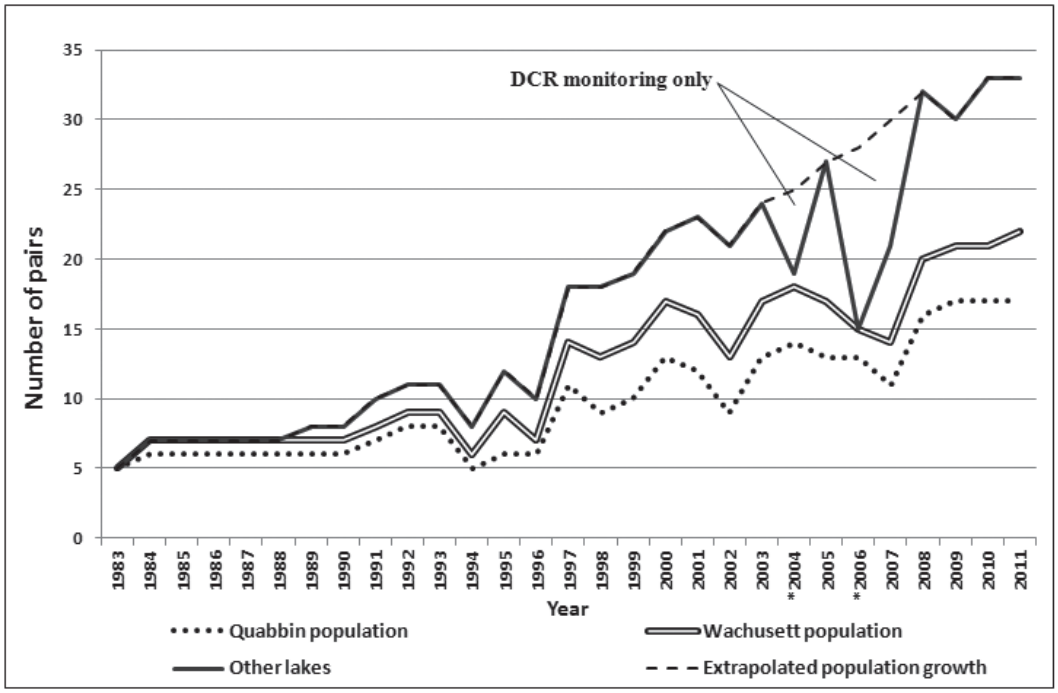

Figure 2. Population growth of Common Loons on the Quabbin Reservoir, Wachusett Reservoir, and other lakes in Massachusetts, 1983-2011. No monitoring was done on non-Massachusetts Department of Conservation and Recreation lakes in 2004 and 2006 so population growth for lakes other than Wachusett and Quabbin Reservoirs was extrapolated.

and signs) were only used twice and were deployed on non-Massachusetts Department of Conservation and Recreation lakes. Raft use by nesting pairs has been high over time, but it is possible that not all raft deployments were recorded in every year. During 1983-2011, raft nests were more successful (CH/NP = 1.10) than natural nests (CH/NP = 0.89) (Z = -3.02, P = 0.001, n = 29 for natural nesting pairs, n = 25 for raft nesting pairs, Mann-Whitney Test).

Carrying capacity based on lake surface area only in Massachusetts was estimated at 370 potential pairs statewide and 322 pairs if depth and phosphorus concentrations were also factored into the analysis. Eliminating Cape Cod, the islands of Nantucket and Martha's Vineyard, and lakes within the limits of large cities due to unlikely dispersal in the foreseeable future resulted in a further reduced estimate of 295 pairs (Table 1). The majority of habitat exists in

Table 1. Common Loon carrying capacity levels for Massachusetts lakes. Pair counts are shown by size class and by successive habitat attributes. Many single-pair lakes are unsuitable when lake depth and phosphorus are accounted for in the estimate.

	Carrying Capacity (K) Estimates			
Size Classes (ha)	K Based on Lake Surface Area Only	K Based on Lake Surface Area + Depth and Phosphorus	Cape, Islands, and Boston Area Excluded From Estimate	Southeastern Massachusetts Excluded From Estimate
124+	118	116	105	82
50-123	116	105	96	76
24-49	93	80	77	67
0-23	43	21	17	15
Total Pairs	370	322	295	240

the 50+ ha size class, 34% of which is located in Worcester County. A large portion of the suitable habitat for Massachusetts is located along the same gradients of habitat that extend from New Hampshire and Vermont.

The Massachusetts and New Hampshire populations during 1983-2011 were not statistically different for nesting propensity, nesting success, and productivity (Table 2). However, they were statistically different for the number of chicks hatched per pair and chick survivorship (Table 2), which likely reflects the difference in survey effort. Management effort and the percent of the population managed were vastly different between the populations with New Hampshire having nearly twice as much management effort during 1983-2011 (Cooley and Vogel 2011). For all demographic rates, Massachusetts had a high degree of annual variation compared to New Hampshire. While the two populations had similar average rates of productivity over time, Massachusetts' starting population of one pair is important to note.

DISCUSSION

The expansion of the loon population in Massachusetts has continued for both the number of pairs and lakes occupied, yet in the past decade productivity as a whole has largely stayed below 0.48 CS/TP. While this is disconcerting, it should have led to a decline in adult numbers over the past few years rather than the observed increase. This may be explained in a few different ways. First, the low productivity in Massachusetts may have been high enough for continued growth if paired with low adult mortality (Mitro *et al.* 2008). Second, productivity over time may have been higher than the data suggest if pairs fledged chicks on lakes not monitored. Lastly, Massachusetts may be benefiting from immigrants as a result of population expansion seen in Vermont and New Hampshire over the past decade (Vogel and Cooley 2010; Hanson 2011).

The results of the carrying capacity estimate are reasonable even though the approach was adapted to accommodate the lack of full explanatory variables used by Kuhn-Hines (2008) and the Loon Preservation Committee (Vogel and Cooley 2010). With a feasible statewide carrying capacity of 295 pairs, there is a large amount of unoccupied habitat as only 14% of available habitat is currently utilized. In Worcester County, loons have not begun approaching habitat saturation as 14 lakes fall into the 124+ ha size class and 20 potential single-pair lakes are still unoccupied. However, two historically single-pair lakes in Worcester County (Pine Hill Reservoir and Lake Wampanoag) recently added second pairs in 2011. Based on expansion dynamics seen in New Hampshire, it can be expected that loons will continue to saturate occupied lakes as well as colonize new lakes in Worcester County (Kuhn-Hines 2008).

The southeastern habitat, including the Lakeville Complex (Great Quittacas, Little

Table 2. Comparison of Common Loon demographic rates and management rates between Massachusetts and New Hampshire, 1983-2011. The two states are significantly different in chicks hatched per pair, management effort, and % population managed. Vermont (VT) productivity average added for additional comparison. Management effort was measured as the number of rafts and exclosures divided by the total number of pairs in a year.

Demographic Rate	Massachusetts Average	New Hampshire Average	Wilcoxon Signed-Rank Results
Nesting Propensity	0.66 ± 0.15	0.66 ± 0.05	$Z = 0.03$ $P = 0.488$ $n = 29$
Nesting Success	0.62 ± 0.23	0.66 ± 0.06	$Z = 0.74$ $P = 0.230$ $n = 29$
Chicks Hatched per Pair	0.74 ± 0.32	1.02 ± 0.11	$Z = 3.49$ $P = 0.002$ $n = 29$
Chick Survivorship	0.83 ± 0.19	0.76 ± 0.05	$Z = 1.66$ $P = 0.049$ $n = 28$
Productivity	0.50 ± 0.26	0.51 ± 0.08	$Z = 0.07$ $P = 0.472$ $n = 29$
		(VT 0.72 ± 0.12)	
Management Effort	0.24 ± 0.13	0.40 ± 0.08	$Z = 3.81$ $P = 0.001$ $n = 25$
% Population Managed	0.16 ± 0.06	0.31 ± 0.07	$Z = 4.45$ $P = 0.001$ $n = 26$

Quittacas, and Assawompset Ponds), is viable loon habitat for long-term conservation considerations. Despite the dispersal distance of about 90 km from Wachusett Reservoir, suitable lakes exist along the way to serve as stepping stones. The establishment of pairs and single adults in the Berkshires about 72 km from the Quabbin Reservoir demonstrates the population's ability to expand over time. The amount of loon activity in the Berkshires could be the result of ephemeral yet productive loon pairs that have gone unrecorded in previous years. Unofficial reports from lake residents of loon pairs and single adults in recent history support this notion.

The core set of lakes in Worcester County and current population structure likely buffers against any short term declines in numbers. Additionally, five lakes have new pairs that either have not nested yet or have been unsuccessful. Single loons occupy six lakes that are likely to change to pair lakes within a few years based on the typical lag time of 3 to 6 years for single loons to form pairs (Loon Preservation Committee, unpubl. data).

The management efforts in Massachusetts have aided population growth, but there is still opportunity for better management. The use of nest rafts by breeding pairs has increased nest success by 27% on average in comparison to natural nests, yet only 24% of territories benefit from rafts. Since nest rafts not only minimize the impacts of water level fluctuations, but also minimize disturbance and shoreline/avian egg predation, even lakes with stable water levels could benefit. Nest rafts may also aid in dispersal of loons to unoccupied suitable lakes (Piper 2002; DeSorbo *et al.* 2007).

The largest factor contributing to the disparity between the Massachusetts and New Hampshire recoveries is the number of pairs in 1975. Having only one pair initially in Massachusetts allowed only minimal growth for a long period of time, regardless of productivity, unlike the 68 pairs in New Hampshire (Vogel and Cooley 2010). While Vermont had a small initial population of just 12 pairs in 1975, it has grown considerably to 98 pairs in 2011 (Evers 2007; Hanson 2011). Since the beginning of recolonization, Massachusetts Common Loons likely suffered from an allee effect due to an inability to find mates or a skewed sex ratio (Allee 1938; Courchamp *et al.* 1999). This phenomenon may be ongoing in the Berkshires region where loon density is very low and occupied lakes seem to change year to year. Although population growth trends suggest continuing recovery, the Massachusetts population may fit some elements of a small population paradigm (Caughley 1994); however, this aspect of population dynamics needs to be investigated further through continued monitoring and population modeling.

The population dynamics of the Massachusetts population have been strong enough to drive growth to this point. Comparisons with New Hampshire show that continued growth is possible, and, as a result, annual variability in demographic rates will likely decrease. It is clear there are conservation opportunities not just in monitoring but also in the management of this population. As a regional subpopulation, Common Loons in Massachusetts have the capacity for continued growth, as demonstrated by productive new and historic territories. The upper limit of 295 pairs is a distant goal, but a 60% (177 pairs) growth toward this goal would be comparable to growth rates in New Hampshire and could be considered a large-scale recovery. It is possible that breeding pairs may colonize large northern Connecticut and Rhode Island lakes if distribution trends continue with further growth and expansion of the Massachusetts population.

Historically, Common Loon populations across North America, particularly in the northeastern United States, declined in response to human influences before rebounding in the middle part of the 20th century (McIntyre 1988; McIntyre and Barr 1997; Evers 2007). This population growth has slowed over the past few decades (Grear *et al.* 2009). Loon populations across the southern extent of the species range have been reported as stable, declining, or slightly increasing (Evers 2007). The recently reestablished and growing Massachusetts population has been an exception to this trend. This may be due to the abundance

of available breeding habitat, which may be dampening density regulation of population growth (Grear *et al.* 2009). The southward range expansion of the Massachusetts loon population is counter to the northern range shifts seen in many bird species and other taxa (Schneider and Root 2002; McDonald *et al.* 2012). Even though Massachusetts loons are reclaiming historically occupied habitat (McIntyre 1988), climate change may influence continued growth and southward expansion of loons. The impacts of climate change on Common Loons need to be studied through increased monitoring in Massachusetts of loon presence and reproductive success, changes in and emergence of parasites and diseases, and changes in prey species. As a population that has been tracked since recolonization, continued monitoring could contribute to research on expansion dynamics and habitat preferences.

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