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Effects of the First Southern Atlantic Hurricane on Atlantic Petrels (*Pterodroma incerta*)

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ABSTRACT.—We report a massive inland displacement of petrels, particularly female Atlantic Petrels (*Pterodroma incerta*) in southern Brazil, after Hurricane Catarina, the first ever reported hurricane in the South Atlantic Ocean. At least 354 petrels were affected and were found in 26 different locations, up to 420 km from the coast and 1,100 m above sea level. Birds were in heavy molt and near starvation, which probably contributed to their displacement and mortality. *Received 2 October 2006. Accepted 4 March 2007.*

The Atlantic Petrel (*Pterodroma incerta*) is a medium-sized gadfly petrel endemic to Gough and Tristan da Cunha islands (Brooke 2004); it has vulnerable global status (Birdlife International 2004) and is one of the least known seabirds (Cuthbert 2004). The global population is ~1.8 million pairs and declining because of low breeding success (20%) due to predation by introduced house mice (*Mus musculus*) on Gough Island (Cuthbert 2004, Cuthbert and Hilton 2004). It is also predated by Southern Skuas (*Stercorarius antarcticus*) on Gough Island and by rats (*Rattus* spp.) on Tristan da Cunha Island (Birdlife International 2004). The pelagic distribution is largely confined to the South Atlantic Ocean with a few records in the Indian Ocean (Enticott 1991, Brooke 2004). Distribution records range from 01° 31′ S, 38° 46′ W off Brazil (Bourne and Curtis 1985) to 65° 12′ S, 41° 05′ W in the Weddell Sea (Orgeira 2001) with most between 20 and 50° S (Enticott 1991). The species is most abundant close to the Subtropical Convergence Zone (Rumboll and Jehl 1977, Veit 1995).

Hurricanes, also called cyclonic storms, typhoons, or cyclones can have severe impacts on populations of vertebrates and invertebrates reducing abundance or extinguishing small populations, as well as extirpating them in more exposed areas (Spiller et al. 1998). Effects on terrestrial birds could be direct, such as death when exposed to strong winds and rain, and displacement to offshore waters or indirect, by increasing predation rates, destruction of nesting and roosting areas, and reduction of food resources (Wauer and Wunderle 1992, Wiley and Wunderle 1993, Collazo et al. 2003, White et al. 2005). The main effects of hurricanes on seabirds are loss of eggs, and mortality of chicks and adults with reduction of breeding success of terns (*Sterna* spp.) and noddies (*Anous* spp.) (White et al. 1976, Langham 1984), direct mortality of adults caused by strong winds (Cely 1991) or petrels and shearwaters displaced inland, particularly in North America (Murphy 1936, Heintzelman 1961, Wiley and Wunderle 1993). Birds found inland are apparently entrapped in the eye of hurricanes and are held away from the periphery of gales (Murphy 1936).

We describe the inland displacement of seabirds after Hurricane Catarina, which hit southern Brazil in March 2004 and provide data on biometry, molt, and body condition of affected Atlantic Petrels. Hurricane Catarina was named after Santa Catarina State in southern Brazil (Fig. 1) and was the first ever reported hurricane in the South Atlantic Ocean (Pezza and Simmonds 2005). It began as an extra-tropical cyclone 800 km from the coast of Brazil (26° S) ~20 March 2004 with minimal pressure inside the eye of 974 hPa (hectoPascal) and a total diameter of 400 km (Pezza and Simmonds 2005). It reached the

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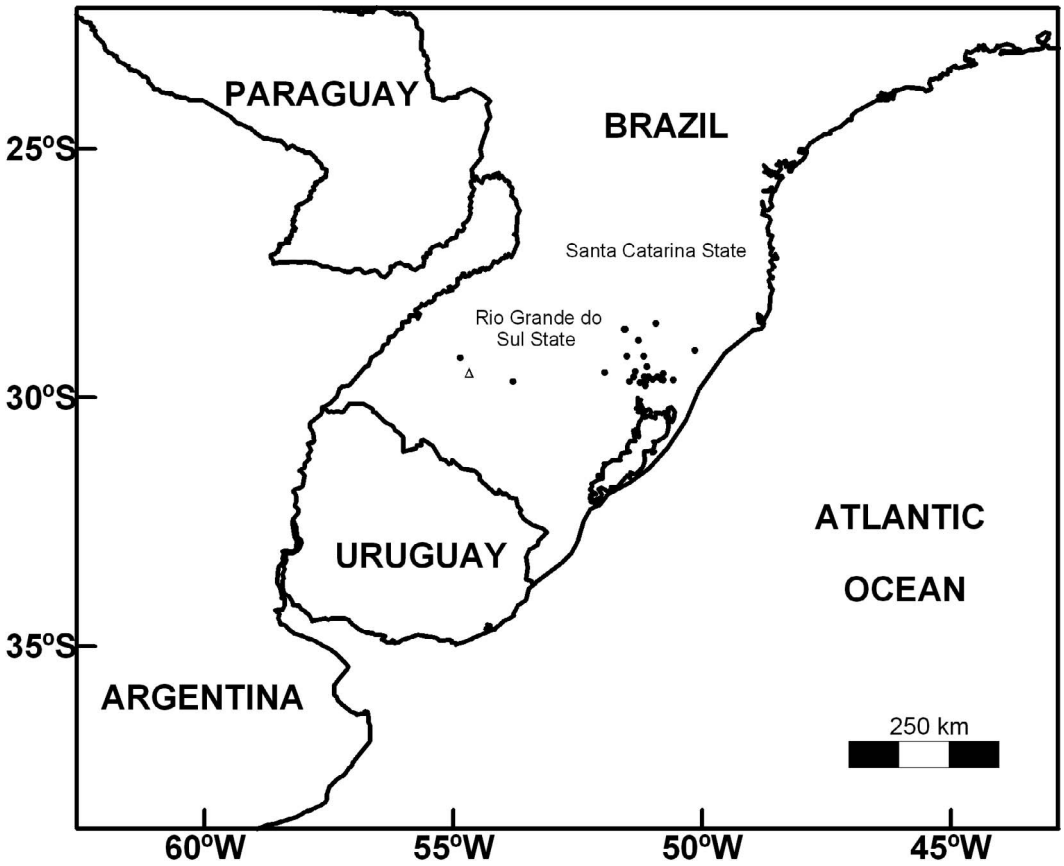

FIG. 1. Inland localities where Atlantic Petrels (dots) and Spectacled Petrel (triangle) were found in Rio Grande do Sul State, southern Brazil after Hurricane Catarina in March 2004.

coast of Rio Grande do Sul and Santa Catarina states on 28 March 2004 with winds from 119 to 153 km/hr and was classified as Category I according to the Saffir-Simpson scale (Pezza and Simmonds 2005). According to local newspapers, the winds destroyed 33,000 houses on the Brazilian coast and sank two fishing vessels in offshore waters.

METHODS

Data where birds were found were obtained by contacting rehabilitation centers. Standard measurements (Proctor and Lynch 1993) and molt status of 29 Atlantic Petrels were recorded, and body condition was assessed by necropsies. Measurements are provided as mean ± standard deviation, range, and sample size (*n*). Wing and tail measurements were not taken from birds molting the outer primaries or central tail feathers, respectively.

OBSERVATIONS

The Atlantic Petrel was the main species affected by Hurricane Catarina. One hundred and twenty-nine Atlantic Petrels and one Spectacled Petrel (*Procellaria conspicillata*) were found inland in Rio Grande do Sul State in an area ~300 km wide and up to 420 km from the coast. They were distributed from sea level to 1,100 m in 26 municipalities of Rio Grande do Sul State (Fig. 1). A flock of 50 Atlantic Petrels also was recovered in a freshwater reservoir used for hydroelectric power production, 190 km from the coast. In addition, another 225 petrels were reported inland in nearby Santa Catarina State, including Giant Petrels (*Macronectes* sp.) and Prions (*Pachyptila* sp.) for which specific identifications were not obtained. Birds from Rio Grande do Sul State were cared for at rehabilitation cen-

TABLE 1. Measurements (mm) and body mass (g) of Atlantic Petrels (*Pterodroma incerta*) displaced inland after Hurricane Catarina in southern Brazil in March 2004. Measurements of males ($n = 6$) and females ($n = 23$) were pooled.

	Mean ± SD	Range	*n*
Total length	416.6 ± 6.8	404–423	9
Wingspan	1,100 ± 20.3	1,080–1,130	5
Wing	323.1 ± 7.7	310–332	7
Tail	134 ± 11	122–154	11
Culmen length	38.1 ± 1.9	35.8–41.3	29
Tarsus length	45.4 ± 1.8	42.4–51.3	29
Body mass	344.6 ± 25.2	310–410	23

ters, but all Atlantic Petrels died within 2 weeks; only the Spectacled Petrel was released back to sea after 10 days. A minimum of 354 birds was recorded, but probably many more were displaced inland undetected.

Measurements of males and females were pooled (Table 1) because they overlap considerably (Cuthbert 2004). Necropsy of birds revealed the Atlantic Petrels were severely emaciated with mean body mass of 344.6 ± 25.2 g (Table 1) and no fat storage. No abnormality of internal organs was macroscopically detected and parasite infections were recorded in the digestive tract of only two birds from 23 examined.

The sex ratio was strongly biased to females (6 males, 23 females; $\chi^2_{\text{Yates}} = 8.83$, $P = 0.003$, df = 1). Females had enlarged ovaries (1–2 mm in length) and 28 of 29 birds were in heavy molt. Twenty-three of 29 birds were molting P9 and/or P10, 26 were molting rectrices (1 to 6 pairs molting simultaneously), and 28 birds (96.6%) had contour body molt. Birds were molting a larger number of rectrix feathers than primary feathers and the pattern of primary molt was more symmetrical than tail molt.

DISCUSSION

To our knowledge, this is the largest number of pelagic seabirds killed by a hurricane, comparable only to the death of 200–400 Brown Pelicans (*Pelecanus occidentalis*) following Hurricane Hugo in 1989 (Cely 1991). This event is not rare in the North Atlantic Ocean where both hurricanes and seabirds in inland areas are more common. Some examples are a Black-capped Petrel (*Pterodroma hasitata*) captured alive in August 1893 in Virginia, USA 2 days after a cyclone. It was found in a fish pond 320 km from the coast and 700 m above sea level, in final molt stage and starving (Smyth 1893). Murphy (1936) described records of Trindade Petrel (*P. arminjoniana*) displaced to Ottawa, Ontario and Ithaca, New York. Heintzelman (1961) recorded a Kermadec Petrel (*P. neglecta*) at Hawk Mountain Lookout, Pennsylvania, USA after Hurricane Gracie in October 1959. In addition, at least three emaciated Atlantic Petrels were collected from a hydroelectric power dam in the eastern Brazilian Amazonia in September 1984 (03° 50′ S, 49° 45′ W), 400 km from the nearest open sea and over 2,000 km from their normal area of occurrence in the western Atlantic Ocean (Teixeira et al. 1986). Overall, *Pterodroma* petrels appear to be more prone to be affected by hurricanes in comparison with other pelagic seabirds.

Measurements were in the range of 54 birds for which data were available from Gough Island (Swales 1965) with the exception of the tarsus, which was consistently longer than for birds from Gough Island (39.1 ± 1.6, 35–43 mm). However, tarsus length in Brazil agrees with 13 males and females measured by Murphy and Pennoyer (1952), which were in the range of 42.1–45 mm. All measurements were in the range for breeding birds provided by Cuthbert (2004). Differences in tarsus length provided by Swales (1965) in comparison with those reported by Murphy and Pennoyer (1952), Cuthbert (2004), and the present study were probably due to different measurement methods.

The mean body mass of birds affected by Hurricane Catarina of 344.6 g (310–410 g) was well below the 522.0 g (440–595 g) reported by Swales (1965) and the 544.4 g (420–720 g) reported by Cuthbert (2004) for birds on Gough Island. Thus, the birds appear to have been starving and could have been suffering from effects of the hurricane for several days. Atlantic Petrels feed largely on squid (87% by mass) (Klages and Cooper 1997) and those examined had obviously not been feeding for several days when inland.

The larger number of females in the sample could be due to differences in at-sea distribution or differences in body condition making females more vulnerable to the storm. The

Atlantic Petrel is a winter breeding species arriving in colonies in late March and departing after 3–4 weeks for a pre-laying exodus of ~50 days (Cuthbert 2004). Most of the Atlantic Petrels were in heavy molt and petrels in general do not molt during their first year. This information, along with the enlarged size of gonads reported here, suggests that petrels found inland in Brazil were ready to return to colonies when they were entrapped by the hurricane. Early accounts of Tristan da Cunha islanders of birds arriving in colonies still molting (Elliot 1957) agree with our data and suggest that molt is completed during the exodus period and before egg laying, which occurs from 15 June to 21 July (Cuthbert 2004).

Patterns of primary molt were more symmetrical than tail molt, consistent with their vital importance for flight in comparison with tail feathers. Langston and Rohwer (1996) suggested that worn feathers or heavy molt could be dangerous, particularly during storms, and Kinsky (1968) suggested that a stranding of 40 Shy Albatrosses (*Thalassarche cauta*) in 1947 was due to heavy molt. Primary molt in petrels is commonly descendant (Marchant and Higgins 1990) and rectrix molt starts after primary molt (Ginn and Melville 1983). Atlantic Petrels displaced by Hurricane Catarina were in late molt stage, which probably was important in depletion of fat reserves and starvation.

Effects of hurricanes on seabird populations are poorly understood, but could be potentially severe when affecting large numbers of endangered species. Hurricanes in the South Atlantic Ocean are postulated to increase in frequency with global warming (Pezza and Simmonds 2005) with potential detrimental effects on endangered species.

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Observations of the Military Macaw (*Ara militaris*) in Northern Oaxaca, México

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ABSTRACT.—We report observations of a population of Military Macaws (*Ara militaris*) within the Tehuacán-Cuicatlán Biosphere Reserve in northern Oaxaca, Mexico during 2002–2004. Macaws used a series of barrancas for roosting and nesting, and foraged widely in surrounding areas. Most of the population of ~100 individuals could be counted flying to or from the major roosting areas of El Sabino Canyon and Barranca de Las Guacamayas. Reproduction appeared to be restricted to vertical cliffs of El Sabino Canyon. Most movements were associated with seasonal foraging and depended upon availability of fruits. *Received 26 August 2006. Accepted 15 March 2007.*

The Military Macaw (*Ara militaris*) occurs in México, Colombia, Venezuela, Perú, Ecuador, Bolivia, and Argentina (Forshaw 1983, Juniper and Parr 1998), and may have once existed in Guatemala. Isolated populations in México have been reported on the Pacific slope from southeastern Sonora and southwestern Chihuahua to Oaxaca and Chiapas, on the Gulf coast in Tamaulipas, and in central Mexico in San Luis Potosí, Estado de México, Querétaro, and Michoacán (Howell and Webb 1995, Iñigo-Elías 2000). Records in Oaxaca are scarce and up to 40 years old, although Binford (1989) reported the species as a rare resident. Recently, *A. militaris* has been found in two zones of the Tehuacán-Cuicatlán Biosphere Reserve; the canyons of the Sabino and Seco rivers within the jurisdiction of the Santa María Tecomavaca and Santa María Ixcatlán communities, respectively, in northern Oaxaca (Salazar 2001). We studied the species in the Biosphere Reserve from 2002 to 2005 to examine feeding and nesting areas, and seasonal movements.

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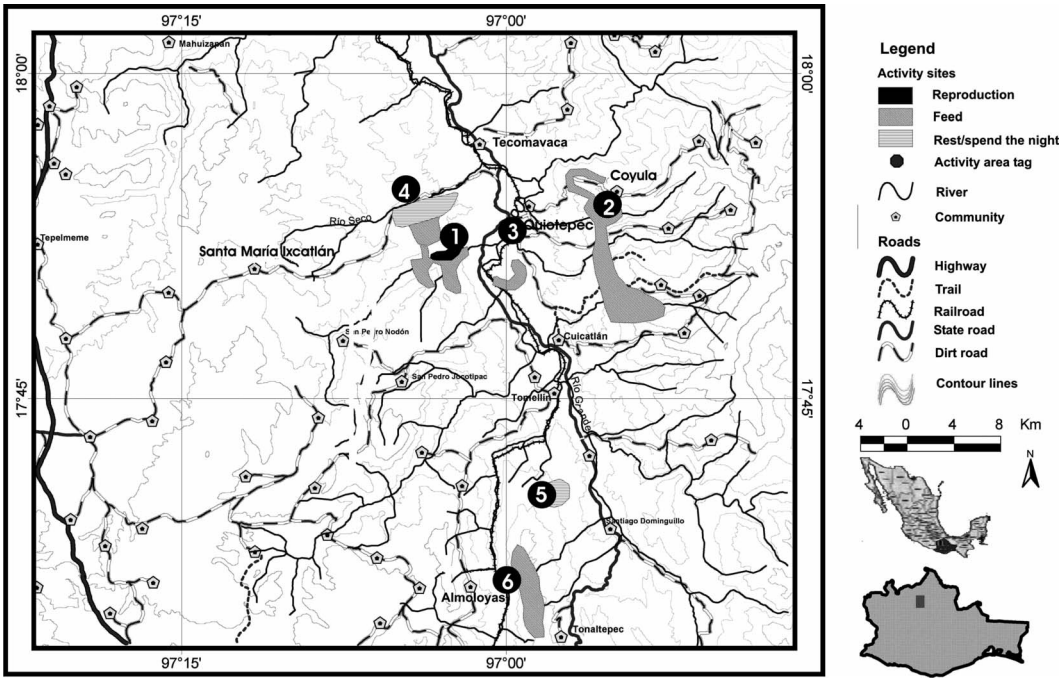

FIG. 1. Sites used by Military Macaws for roosting, reproduction, and foraging in the Tehuacán-Cuicatlán Biosphere Reserve in northern Oaxaca, México. (1) El Sabino Canyon, (2) Coyula, (3) Quiotepec, (4) Barranca de Los Compadres, (5) Barranca de Las Guacamayas, and (6) Almoloyas.

METHODS

The study area is within the Tehuacán–Cuicatlán Biosphere Reserve in northern Oaxaca, Mexico from 17° 30′ N to 18° 01′ N and 96° 50′ W to 97° 18′ W (Fig. 1). The topography of this area is complex, ranging from 520 to 2,850 m elevation. The area is part of the floristic provinces of the Tehuacán-Cuicatlán Valley (García and Torres 1999). We located areas used by macaws from ground surveys, and interviews with authorities and members of local communities. We conducted explorations and simultaneous observations at all sites between 2002 thorough 2004 to ensure that counts were from the same population, and to eliminate the possibility that more than one population was present. Each site was visited at least every third week for 2 days until all macaws had moved from the area. We chose an observation location with long distance visibility at each site to make population counts, and record daily movements between night roosting or nesting sites, and feeding sites.

OBSERVATIONS

Military Macaws primarily used the northern part of the study area from January until August for nesting and foraging. The most important sites used were El Sabino Canyon, Coyula, Quiotepec, and Barranca de Los Compadres. Macaws used the southern part of the study area from late September to December, primarily Barranca de Las Guacamayas for roosting at night and Almoloyas for foranging (Fig. 1). Macaws, like other psittacines, are gregarious, but movements between sites were not simultaneous. Instead, site use was low initially with only a few pairs observed, but within 2-3 months, the entire population could be counted (~100 individuals) at some sites.

El Sabino Canyon.—The Sabino River forms a deep canyon with walls 250 m high (17° 51′ 43.2″ N, 97° 02′ 37.5″ W) (Fig. 1). The predominant vegetation is tropical deciduous forest and xerophytic scrub (*tetecheras* and *cardoneras*). This is the only area where macaws have been observed to nest in the study area and was used mainly from January

through September. The entire population uses this site for roosting at night from April into July and forages in adjacent areas from May through July. Nests occur in holes in the walls of the canyon, similar to those used by Maroon-fronted Parrots (*Rhynchopsitta terrisi*) (Macías 1998).

Coyula.—This is a small area leeward in the highest region of the Sierra de Juarez, south of the canyon of the Santo Domingo River, in an area that has continuously strong winds (17° 54′ 40.3″ N, 96° 56′ 11.5″ W) (Fig. 1). The vegetation in the area is a combination of tropical deciduous and humid oak (*Quercus* spp.) forest. These ecosystems differ in species composition from that commonly observed in the larger Oaxaca glen. The area is used by macaws from January through April for foraging during the morning and part of the afternoon. We have observed more than 50 individuals in this area, mostly during March and early April.

Quiotepec.—This area is near the dirt road connecting the towns of Quiotepec and Cuicatlán in proximity to the Grande River (17° 51′ 45.1″ N, 96° 59′ 13.9″ W) (Fig. 1). Habitats in this area are a mixture of riparian vegetation and lemon, mango, and anona plantations. It also contains tropical deciduous forest intermingled with xerophytic scrub from 50 to 100 m from the river. Columnar cacti such as *Myrtillocactus geometrizans*, *Pachycereus weberi*, and *Acacia cochliacantha* occur in the xerophytic scrub. This is a foraging area used during the day for some pairs from April through August. However, the entire population spends the night in El Sabino Canyon and forages in the surrounding areas. This is an intermediate area between Coyula and areas surrounding El Sabino Canyon.

Barranca de Los Compadres.—This area is on the old road to Santa María Ixcatlán (17° 54′ 9.1″ N, 97° 4′ 27″ W) (Fig. 1). It is characterized by vertical walls more than 100 m in height surrounded on the east by more or less flat surfaces and on the north by the Seco River. The predominant vegetation is tropical deciduous forest. This is a foraging and night roosting area used from July through October. Macaws primarily used two sites (Barranca de Las Guacamayas for night roosting and Almoloyas for foraging) south of the study area from late September to December.

Barranca de Las Guacamayas.—This area is a gorge with vertical walls of ~50 m southwest of the community of San José del Chilar (17° 40′ 44.6″ N, 96° 58′ 17.9″ W) (Fig. 1). The vegetation is mostly tropical deciduous forest. Macaws first arrive in this area in September and use it for night roosting until December. This area and El Sabino Canyon are the only sites where the entire population occurs together at a given time.

Almoloyas.—This area is in the southern part of Tomellin Canyon between the El Venado and Almoloyas railway stations (17° 38′ 15.7″ N, 96° 59′ 52.2″ W) (Fig. 1). The area contains tropical deciduous forest and xerophytic scrub, and is mostly natural as it is far from urban areas and roads. It has been identified as an isolated area with high endemism (Villaseñor et al. 1990, Dávila et al. 1995). It is used by the entire macaw population for foraging during those months when macaws roost in the Barranca de Las Guacamayas area.

DISCUSSION

The best and more consistent and robust counts of the population were in roosting sites because of the behavior of macaws in flying in morning to foraging sites and late in the afternoon to roosting sites. Thus, simultaneous observations can be used with confidence to identify the close relationship between areas used by macaws. There is no other known population of macaws to the north or south and there is no potential habitat to use to the west or east of the study area. We believe this population of *Ara militaris* is an isolated population.

The Military Macaw population in the areas surveyed is ~100 individuals. Macaws used feeding areas sequentially from the farthermost area east to that closest to El Sabino Canyon during the reproductive season in the first half of the year until they began to abandon the canyon from July to September. At this time, approximately half of the population spends the night in the Barranca de Los Compadres.

The first of the seasonal movements occurs at the end of the nesting season during August through October when the population leaves El Sabino Canyon and the Barranca de Los Compadres, and disperses over the region be-

fore joining in the Barranca de Las Guacamayas, south of the study area. The reverse movement occurs from January to April when the population joins in El Sabino Canyon.

The dominant vegetation in the area is deciduous forest and macaws may be found almost anywhere at any time of the year, but with obvious trends in use of some areas. The average maximum flight distance in a day is ~20 km allowing macaws easy access to a variety of resources and potential foods. We suspect that much of their flight activities provide information on the status of foods and it appears that macaws can readily take advantage of locally abundant food sources. However, they appear to be able to cope with irregularities in fruiting schedules of their major foods. Seasonal movements are the logical response to a diet based on fruit. The flexibility of movement patterns is also logical, given year to year fluctuations in plant productivity and the patchy distribution of important food plants throughout the range of macaws (Snyder et al. 1987). Seasonal movements are likely a response to breeding and availability of specific food resources similar to other psittacines (Symes and Perrin 2003).

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