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Aboriginal Burning Regimes and Hunting Strategies in Australia's Western Desert

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A large complement of Australia's biotic web is dependent on a regular regime of burning, much of which is the result of firing by humans. Many researchers have suggested that moderate and repeated burning by Aborigines is a tool designed to enhance hunting efficiency. We present the first test of this with data on contemporary Martu Aboriginal burning and hunting strategies in the arid spinifex savanna of the Western Desert during the cool-dry season (May–August). Our results show a strong positive effect of mosaic burning on the efficiency of hunting burrowed prey (primarily conducted by women), but not larger mobile prey (primarily conducted by men). We suggest that regular anthropogenic disturbance through burning in Australia's Western Desert may be important for sustaining biodiversity and habitat mosaics, but these effects may be maintained primarily by women's hunting of burrowed game. We discuss the implications of these results for understanding variability in hunting strategies, issues of conservation, and land management policy for the region.

KEY WORDS: Martu Aborigines; habitat mosaics; burning strategies; women's hunting; Australia.

INTRODUCTION

The central role of fire in the terrestrial biodiversity of Australia is widely acknowledged (e.g., Bowman, 1993, 1998; Bowman and Latz, 1993; Bowman and Panton, 1995; Bradstock *et al.*, 2002; Gill *et al.*, 1981; Hayen *et al.*, 2000a,b; Latz, 1996; Nodvin and Waldrop, 1990; Russell-Smith *et al.*, 1997a,b; Russell-Smith and Bowman, 1992). However, we have a limited

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understanding of the factors that determine the decisions that Aborigines make in maintaining landscape burning regimes (see review in Bowman, 1998, pp. 389–390). Discussions of Aboriginal firing practices have generally focused on three interrelated aspects: 1) possible changes in burning regimes indicated by paleoecological records coincident with the arrival of humans in Australia, and subsequent changes in vegetation demography and distribution (see Bowman, 1998; Kershaw *et al.*, 2002; O'Connell and Allen, 1998, for recent summaries and debates); 2) the relationship between firing, the primary extinction of Pleistocene mega fauna, and historic declines and extinctions of small-to-medium sized marsupials (Allan and Southgate, 2002; Bolton and Latz, 1978; Bowman, 1998; Burbidge and McKenzie, 1989; Burbidge *et al.*, 1988; Burrows *et al.*, in press; Clark, 1983; Flannery, 1990, 1994; Horton, 1982; Lundie-Jenkins, 1993; Morton, 1990; Saxon and Dudzinski, 1984; Short and Turner, 1994; Southgate *et al.*, 1997); and 3) the role of Aboriginal burning as a general land management strategy for increasing food supplies and maintaining wildlife habitats (see review in Bowman, 1998, pp. 390–394; also Allan and Southgate, 2002; Gould, 1971; Jones, 1969, 1975, 1980; Nicolson, 1981; Pyne, 1991; Russell-Smith *et al.*, 1997a,b; Short and Turner, 1994; Yibarbuk *et al.*, 2001). Our aim is to address the fire management issue with data on the immediate and long-term benefits accruing to Martu Aborigines in the Western Desert of Australia.

There is now considerable evidence that regular fire treatment in the spinifex (*Triodia* spp.) savanna of the Western Desert increases the richness of plant species, decreases the potential for devastatingly large wildfires, and has an important impact on faunal populations (Allan and Southgate, 2002; Allan and Barker, 1990; Bolton and Latz, 1978; Griffin, 1992; Haydon *et al.*, 2000a,b; Latz, 1996; Lundie-Jenkins, 1993; Southgate *et al.*, 1997; see Laris, 2002, for similar effects in Africa). Long periods without fire lead to profound changes in the landscape. After Aboriginal burning ceased in the eastern part of the Western Desert, from 1953 to 1981 the number of recently burnt patches fell from 846 to 4, while the mean burnt patch size went from only 64 ha to 52,644 ha (Burrows *et al.*, 2000). Diverse mosaics attract game, so it is not surprising that a number of researchers have argued that Aboriginal burning strategies (and associated beliefs) are designed to create mosaic habitats, stabilize resource populations, and/or maintain diverse assemblages of game and vegetation (e.g., Burbidge *et al.*, 1988; Burbidge and McKenzie, 1989; Gould, 1971; Jones, 1969, 1980; Russell-Smith *et al.*, 1997a; Yibarbuk, 2001).

In much of arid Australia burned savanna is quickly colonized by short-lived grasses, forbs, and insects, many of which are important food resources for both humans and large game animals such as bustard

(*Eupodotis australis*), emu (*Dromaius novaehollandiae*), euro (*Macropus robustus*), and plains kangaroo (*Macropus rufa*) (Latz, 1996). For anthropologists, a good deal of attention to the benefits of burning savanna has focused on hunting larger prey (e.g., Gould, 1971; Jones, 1975, 1980; Kimber, 1983). Regular burning is assumed to increase edible forage and facilitate flushing these animals; thus hunting success should peak with the use of fire and one or two years following a burn. However, no tests of this hypothesis have ever been conducted using actual observations of Aboriginal hunting and burning strategies. We intend to provide the first quantitative data to test the hypothesis that cultural knowledge about burning functions specifically to increase the efficiency of hunting large, mobile prey.

BACKGROUND AND METHODS

The term Martu (or Mardu in many orthographies) conventionally refers to foraging groups whose traditional estates surround Lake Disappointment, the Rudall River, and the Percival Lakes in the northwest section of the Western Desert (Fig. 1, see Tonkinson, 1991, 1974; Walsh, 1990). Today, the Martu (numbering about 600–800 people) consist mostly of speakers of Manyjilyjarra, and Kartujarra dialects.

Limited contact between a few Martu and white explorers and settlers began in the early 20th century with pastoral efforts on the western and southern fringe of Martu territory. In the 1930s some Martu began a process of migration westward from their desert estates, visiting and eventually settling around Jigalong (a maintenance depot, and later Protestant mission; see Tonkinson, 1974, for detailed history). However, many families, especially those from the easternmost part of Martu territory, remained in the heart of the desert until the mid-1960s, when prolonged drought and continuing depopulation drew them into Jigalong and neighboring pastoral stations. While many Martu stayed in European settlements, many also left soon after their arrival. In the mid-1980s numerous families (mostly those that were the last to leave the desert) returned permanently to their desert homeland. By 1986 they had established two permanent "Outstation" camps (Punmu and Parnngurr) in the newly designated Rudall River National Park (another outstation at Kunawarritji, Well 33 on the Canning Stock Route, soon followed). Many Martu felt that their ability to keep sacred Law and practice their religion depended on moving back to their homelands (Tonkinson, 1991, pp. 174–178).

Especially for the families at Parnngurr (comprising a core population of about 100 people), their return to the desert meant a return to a foraging economy. Government rations were trucked out when possible, but often

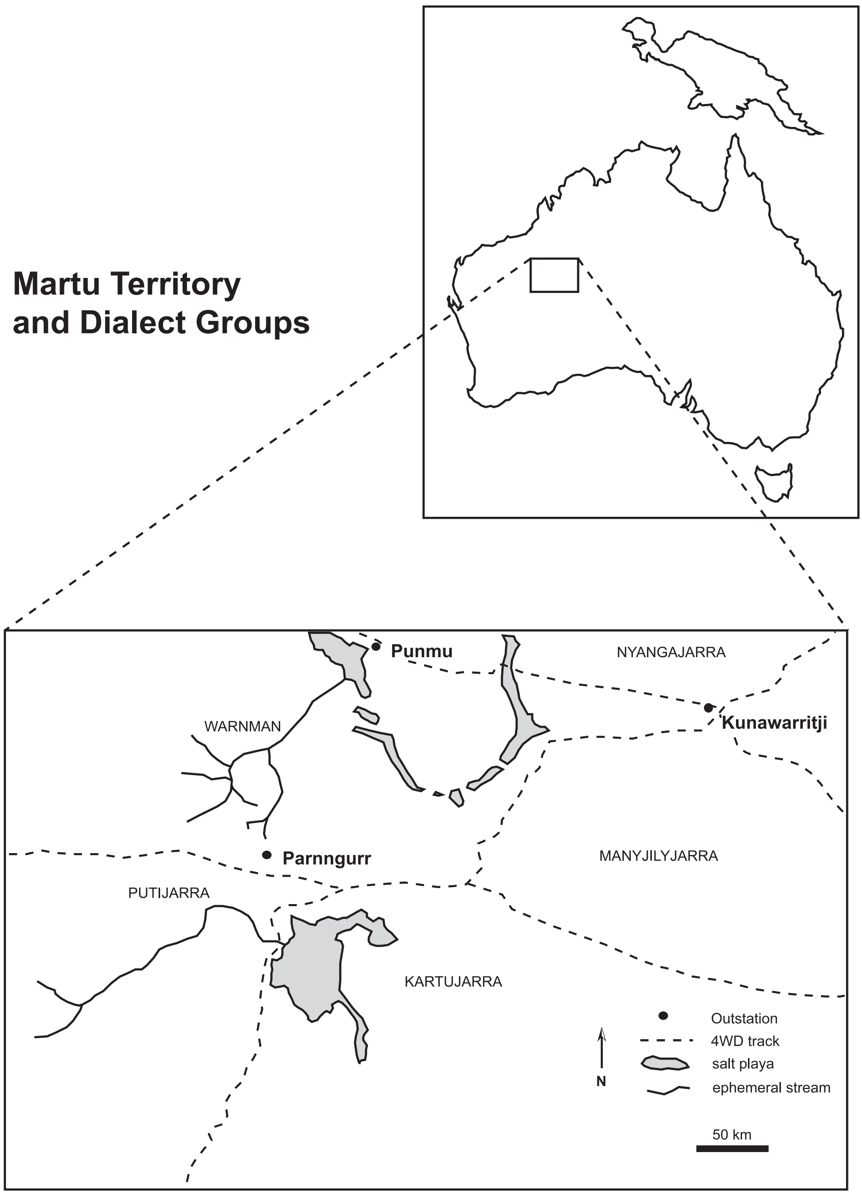

Fig. 1. Map of Martu territory and dialect groups.

vehicle access to the camp was cut off for months at a time. Throughout the mid-late 1980s and early 1990s, much of the daily subsistence at Parnngurr came from hunting and gathering. Walsh (1990, and Veth and Walsh, 1988) conducted critical research on foraging activities in and around Parnngurr during this period, focusing on Martu ethnobotany, seasonal variability, and gathering ecology.

Today, the importance of foraging has declined somewhat compared to what it was at Parnngurr's establishment. The supply route to the community is more reliable (although still precarious, especially during summer rains), regular government funds (e.g., social security and Community Development Employment Program (CDEP)) and a small store (usually well-stocked with basic food and household items) have increased reliance on a cash/welfare economy. With permanent settlement, foragers now require vehicles to visit more distant hunting and gathering grounds on day trips, and there are few working 4WD trucks in the community. Martu also face increasing demands on their time: with sedentism, clothing, and vehicles came the need to allocate more time to cleaning, washing, and maintenance; men and women are often involved in ritual activity, with some men spending months at a time away from the community; time is also taken up with various government meetings and functions; and obtaining CDEP wages means at least some time working during the week on various community projects. Nevertheless, Martu at Parnngurr continue to hunt and gather on a regular basis, their foraging frequency limited primarily by their access to vehicles and fuel. Although most people at Parnngurr would like to hunt nearly every day, the majority forage about 3–4 days out of the week. Foraging trips to "dinner-time camps" within 50 km of the community occur nearly every day, and extended camps to more distant locales are common, especially during the cool-dry season (sp. *Wantajarra*, May–August).

Most of our time with the Martu has been spent in Parnngurr and on extended camps away from the Outstations. Foraging locales are usually accessed with a vehicle, after which women and children hunt and gather on foot with digging sticks, while men often utilize vehicles and small gauge rifles. On average, 25%–50% of the total diet comes from bush foods, and on foraging days bush foods make up 80% of the diet per participant (Bliege Bird and Bird, unpublished data).

The data presented here were collected in 2000–2001 during camps away from the Outstation communities. The analysis covers 422 forager-days in the cool-dry season. We limit the analysis below to *Wantajarra* hunts: foraging during the other seasons does not usually involve burning large tracts of grassland (analyses of seasonal differences are currently underway, but see Walsh, 1990). All Martu participants apart from the younger children spent most of their lives in the desert and all of their formative years as full-time foragers. Camps averaged 10.5 individuals, ranging in age from 3 to approximately 70 years old. A total of 6,882,519,706 kcal of meat, insects, fruit, roots, and nectar were collected during these camps, averaging 1792 ± 279 (SE) kcals per forager-day (including all children). Researchers supplied an average of 350 kcals per participant-day, primarily in the form of flour and sugar.

Foraging Follows

During extended camping trips we conducted daily detailed focal individual foraging follows. Each researcher asked permission to accompany a camp member over the course of the day, during which we recorded the time a forager spent *traveling* to and from a foraging locale, *searching* for a range of potential resources, *tracking* a particular prey item, *capturing* a particular item, and field *processing*. We then recorded the weight of each animal captured, the parcel harvested, and the total weight of the catch by resource type at the end of the day. A total of 252 adult focal follows (165 women, 87 men, consisting of 33 different individuals) are used in the analysis below (for children's foraging see Bird and Bliege Bird, in press). In addition to the focal follows, during each camp day we recorded the duration of all foraging trips in camp and the weight (by item or type) of all food captured by all participants in camp. Edible weights for animals were calculated in the field by weighing uncooked specimens and asking participants to discard the post-consumption waste material from the animals into a receptacle. Since much of the variability in energy per animal is a function of animal fat, we estimated an average value for the percentage of fat by weight based on the weights from dissected cooked individuals of each prey type. All weights were obtained with hand-held tubular spring scales accurate to ± 5 g. Energy values were taken from published sources analyzing the composition of Aboriginal foods (Brand Miller *et al.*, 1993). As used below, foraging *efficiency* (overall foraging return rate) is measured as the gross edible energy gained per focal individual follow divided by the total time the forager spent in search, tracking, and capture.

Burning Regimes and Habitat Mosaic

Sandplains and dunes dominate Martu landscapes. Areas that have remained unburned for longer than 3 years are dominated by (>80%) old growth spinifex grass (*Trodia* spp.) with characteristic "donut" shaped hummocks (Latz, 1996, p. 10). Martu systematically fired older growth spinifex at nearly every camp. Following a fire, the proportion of visible spinifex is reduced to nearly zero, and with any rain, plant diversity (e.g., *Solanum, Eragostis, Dysphania, Trichodesma,* and *Evolvulus*) in a recently disturbed patch increases dramatically. Martu pay close attention each fire: most adults can recount when, where, and by whom every fire was lit (with details of fire intensity and progression) over at least the three previous seasonal cycles within a radius of about 100 km from the three Outstations. Martu also regularly classify regrowing habitat according to its utility: *nyurnma* (a recently burnt area with no regrowth), *waru-waru* (herbaceous plants are regrowing, generally following a vain), *mukura* (herbaceous plants have reached maturity), *mangul* (herbaceous plants are declining, spinifex is dominating), and *kunarka* (very mature spinifex-dominated community). Depending on rainfall, spinifex sand habitats can take up to 10–20 years to reach *kunarka* stage.

To characterize habitat mosaic and burn regimes we chose a straight 2 km transect in a random direction from each camp. A researcher walked the transect and noted the number of times they passed from one patch of vegetative regrowth to another. *Fine-grained mosaics* around camps were defined as those in which a researcher passed into three or more types of regrowth patches on a single transect. This type of mosaic results from moderate anthropogenic burns at regular intervals. For fine-grained mosaics Martu recounted lighting at least one fire-line in a 10 km radius of the camp within at least the previous two seasonal rounds. *Medium-grained mosaics* at camps are defined as habitats in which a researcher passed into two patches of regrowth on a transect. These habitats result from larger fires (some greater than 20 km^2), usually at intervals of >3 years but <10. *Coarse-grained mosaics* around camps are dominated by a single patch: either old-growth spinifex (>3 years old) over a very large area, or a recent very large burn (>50 km^2) (Haydon *et al*., 2000a). In these areas a researcher never crossed into another stage of regrowth over a 2 km transect. In rare cases, prior to firing, Martu indicated that the area around the camps had not been burned (from their own ignition or by lightning) in over 10 years.

RESULTS

Especially in fine-grained mosaics, Martu often encounter and collect a wide array of fruits (especially *Solanum* spp.), roots and tubers (*Vigna lanceolata* and *Cyperus bulbosus*), larvae (*Cossid* spp.), nectar (primarily *Grevillea eriostachya*), and grass, shrub, and tree seeds (especially *Eragrostis eriopoda* and *Acacia* spp.) (Tonkinson, 1991; Veth and Walsh, 1988; Walsh, 1990). Analyses of these other aspects of Martu foraging are currently underway. For the purposes of this analysis we focus on differences between the major *Wantajarra* "hunt types" (sensu Smith, 1991): *wana hunting* for burrowed game and *gun hunting* for mobile game.

Hunt Types and Sex Differences: Wana Hunts Versus Gun Hunts

Martu hunt for burrowed game on foot with a *wana* (wooden or iron digging stick) exclusively in sandplains and dunes. During the *Wantajarra* season these hunts almost always incorporate burning tracks of spinifex savanna to clear the overburden and facilitate the lengthy search for tracks and dens. *Wana* hunters search mostly for burrowed sand goanna (*Veranus gouldii*), but also python (*Aspidites* spp), skink (*Tiliqua multifasciata*), feral cat (*Felis silvestris*), and ridge tailed goanna (*V. acanthurus*) (Bliege Bird and Bird, in press). Burning during *wana* hunts is highly systematic: the size of the fire-line used and the burned patch (*nyurnma*) that results depend on the wind velocity, accumulated fuels, and surrounding firebreaks—in the sandplains and dunes, firebreaks are primarily neighboring patches burned within the last two or three years. Hunters ignite a line of dry spinifex by quickly flicking matches or dabbing a fire-stick into the occasional hummock as they walk along in search. With the ignition of a fire line, a hunter will immediately begin to search for tracks and fresh dens within the *nyurnma*, often following along just behind the advancing flames in the clear surface of new ash. Ideally this creates a *nyurnma* of about 5 km^2. Generally each hunter will light his/her own line and search independent of others, although they often signal to each other in managing their burns and cooperate to extract prey from their dens. Tracking and capturing burrowed prey requires tremendous skill: highly specialized cues are used to determine the freshness of tracks and detailed knowledge is require to detect and probe for an occupied den.

Hunting with a gun focuses on larger, more mobile game. It is typical "encounter" hunting with long-range search (in vehicles and on foot) across sandplains, low lying rocky ranges, watercourse margins, and mulga flats for various types of prey. If a vehicle is used, usually there is a driver and a shooter; if they hunt on foot, they usually do so alone. Tracking often involves the pursuit of a particular animal over long distances. Sometimes a single animal will be tracked over the course of a number of days. During *Wantajarra* Mardu mostly capture bustard (*Eupodotis australis*), but when encountered they also track and capture feral cat, euro (*Macropus robustus*), plains kangaroo (*Macropus rufa*), emu (*Dromaius novaehollandiae*), and occasionally perenti (*V. giganteus*) (Bliege Bird and Bird, 2005). Game is generally taken with small gauge rifles (although spears and throwing sticks are still used on rare occasions). Some larger animals are attracted to recent burns or the new vegetation that follows, but burning is not generally used to find and capture mobile game. Gun hunts cover numerous habitats over long distances, and a large burn can reduce the cover and increase the probability that an animal will detect the hunter. Martu do sometimes burn in the course of these hunts, but usually to flush game rather than to facilitate searching and tracking. Due to differences in technique and technology, *wana* and gun hunting are for the most part mutually exclusive activities.

During the cool-dry *Wantajarra,* women spent as much time hunting (defined as time spent searching, tracking, and capturing game) as men, but each sex hunted differently (Fig. 2). Women spent 179 ± 15 (SE) min per forager-day *wana hunting* (usually accompanied by other women), and only 9 ± 6 min *gun hunting* (usually accompanied by men). Men spent 108 ± 16 min per forager-day *gun hunting*, and 83 ± 19, min *wana hunting*. The differences in time allocation of men and women to the two hunt types are significant (one sample *t*-test, Male vs. Female *wana* hunting: DF = 33, $t = -5.403$, $p = .0001$; Male vs. Female gun hunting: DF = 33, $t = 6.099$, $p = .0001$).

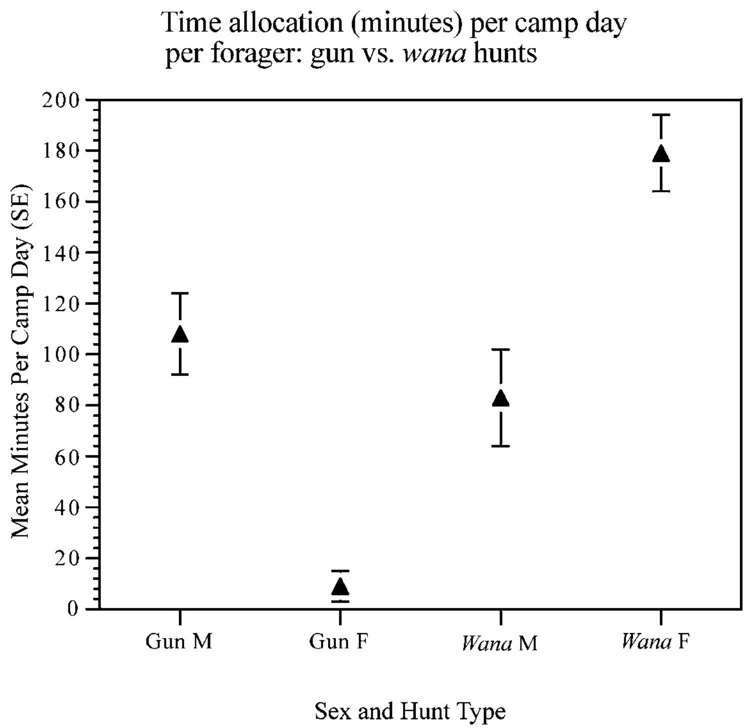

Fig. 2. Time allocated (minutes/forager-day ± SE) by men (M) and women (F) to hunting for gun hunting vs. *wana* hunting.

Burning and Hunting Efficiency

Even though much discussion about the Aboriginal use of fire has focused on its benefits in men's hunting, gun hunters burned on only 11% (10/87) of foraging follows. Gun hunters did not significantly increase their foraging efficiency if they burned while foraging: they obtained 2377 ± 1036 kcal/foraging-hr ($n = 8$) after lighting a fire line, and 2178 ± 1064 kcal/hr ($n = 77$) if no burning occurred ($t = .067$, $p = .947$) (Fig. 3).

However, firing the spinifex savanna had immediate and significant effects on the efficiency of women's *wana* hunting for burrowed game: burning resulted in 575 ± 35 kcal/foraging-hr ($n = 113$), while hunting without burning produced only 409 ± 63 kcal/hr ($n = 52$) ($t = 2.47$, $p = .014$) (Fig. 3). When we compare the expected returns of burning and hunting during *wana* hunts with that of gun hunts, gun hunting is associated with higher efficiency (DF = 198, mean difference = 1626, $t = -1.95$, $p = .052$). However, gun hunting is also associated with over seven times the variance of *wana* hunting. Gun hunters failed to capture prey on 68% of the focal follows; *wana* hunters failed on only 3% of the follows. As a result of these differences in variance, a non-parametric test reveals that the efficiency of *wana* hunting for burrowed game ranks significantly *higher* than gun hunting ($U = 2659$, $p < .001$, mean rank for *wana* hunts = 121, mean rank for gun hunts = 75).

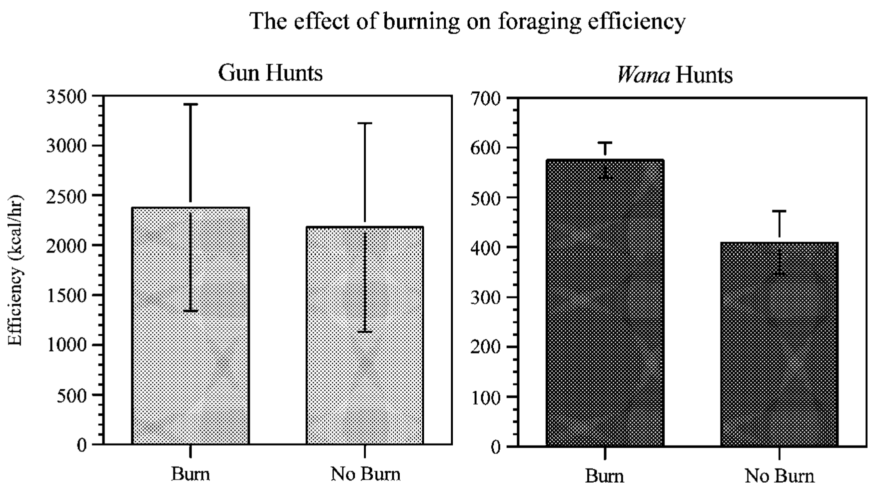

Fig. 3. The effect of burning on hunting efficiency (kcal/hunting-hr ± SE): gun hunting and *wana* hunting.

Habitat Mosaic and Hunting Efficiency

If mosaic grain influences the distribution and abundance of indigenous animals, it should have an effect on hunting efficiency (Yibarbuk *et al.*, 2001). Our results show that there were no significant effects on gun hunting efficiency according the mosaic grain of the habitat (ANOVA, $df = 84$, $f = .124$, $p = .884$) (Fig. 4). Gun hunters obtained their lowest hunting returns in fine-grained mosaics (1174 ± 784 kcal/foraging-hr, $n = 10$ hunts), and their highest hunting returns in both medium (2058 ± 667 kcal/foraging-hr, $n = 44$) and coarse-grained mosaics (2701 ± 2345 kcal/foraging-hr, $n = 33$). Games-Howell post-hoc test at $\alpha = .05$ between showed no significant differences in efficiency with mosaic grain treatment ($p = .640 - .778$).

The opposite pattern was observed for *wana* hunting: mosaic grain had a significant effect on foraging efficiency (ANOVA, $df = 162$, $f = 19.00$, $p < .001$) (Fig. 4). The highest efficiency was obtained in fine-grained mosaics (656 ± 40 kcal/foraging-hr, $n = 97$), significantly lower

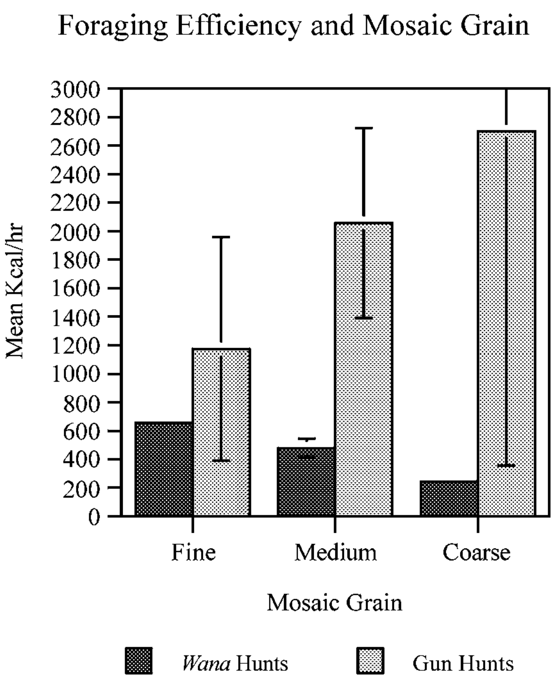

Fig. 4. The effect of mosaic habitat grain on hunting efficiency (kcal/hunting-hr ± SE): gun hunting and *wana* hunting.

returns in medium-grained mosaics (480 ± 67 kcal/foraging-hr, $n = 25$), and lower returns still in coarse-grained habitats with long fire intervals (246 ± 47 kcal/foraging-hr, $n = 43$). A Games-Howell post-hoc test at $\alpha = .05$ between treatments (habitat mosaic) resulted in significant differences between fine-grained and medium-grained habitats (mean difference = 177 kcal/foraging-hr, critical diff = 162, $p = .033$), between fine-grained and coarse-grained habitats (mean diff = 411 kcal/foraging-hr, critical diff = 132, $p < .001$), and between medium-grained and coarse-grained habitats (mean diff = 234 kcal/foraging-hr, critical diff = 181, $p = .012$).

DISCUSSION

The Issue of Variability in Hunting and Burning Strategies

Short-Term Benefits

The Martu data demonstrate clear sex differences in hunting strategies during *Wantajarra*: men focus on gun hunting for mobile game, women focus on hunting burrowed game with a *wana*. While men's gun hunting yields higher *average* efficiency, it is associated with a high risk of failure. Thus, women's *wana* hunting is more *predictably* efficient than gun hunting.

The data also show that when they burn, *wana* hunters benefit more (and more predictably so) than gun hunters. Without firing tracts of spinifex savanna, the efficiency of *wana* hunting for burrowed game is significantly and immediately reduced. Finding tracks and dens of burrowed game while searching in old growth spinifex is very difficult. As such, *wana* hunters failed to burn only on those occasions when they were hunting near ritual sites that proscribed burning or when members of the foraging party were not within their own estates (see Tonkinson, 1991). However, we can detect no such effect on gun hunting: given the variability in efficiency, men's return rates while hunting for mobile game did not change with burning.

These results suggest to us that women's hunting strategies may often be designed for more reliable meat provisioning, while men's foraging goals may include other motivations (social attention and religious obligation, see Bliege Bird and Bird, 2005). Younger men are often required to hunt larger mobile game for their elders (Tonkinson, 1991), and this may have little to do with a "sexual division of labor" designed to reliably provide meat for themselves or others. Testing this will require much more research into the relationship between foraging activities, food sharing, and "social capital" (e.g., Bliege Bird, 1999; Bliege Bird *et al.*, 2001; Hawkes and Bliege Bird, 2002; Smith *et al.*, 2003).

Long-Term Benefits

While the immediate benefits of burning during *wana* hunts are clear, some caution should be used in interpreting the long-term relationship between hunting efficiency and habitat mosaic. Thus far we only have a rough measure of habitat mosaic at each camp, and 2 km transects are unlikely to capture the full range of mosaics encountered by hunters. Further investigation into the relationship between habitat mosaic, burning patterns, and foraging efficiency will require large-scale measures of habitat mosaic and burning regimes with remote sensing and GIS technologies and associated variability in the efficiency of foraging for all types of resources. Nevertheless, at the coarse-grained end of the habitat mosaic continuum, the results are intriguing. In these habitats hunters were searching in areas that had not been burned for many years, so they spent all of their time in either old growth spinifex or very large-scale recent burns with little or no regrowth. There, *wana* hunters experienced significantly lower return rates than in fine-grained mosaics. These patterns were not observed for men's gun hunting. While a "patchier" environment from moderate burning might make mobile game more predictable in time and space (see Lundie-Jenkins, 1993; Yibarbuk, 2001), these effects on gun hunting efficiency are muted by definition: game is *mobile* across numerous patches. As such, the impact of burning and the creation of habitat mosaics on mobile game populations is difficult to detect. Relative to *wana* hunting, gun hunting is inherently unpredictable—for both hunters and analysts.

In our study, bustard and kangaroo were the primary mobile prey obtained by men on gun hunts. Martu men often remarked that these game are attracted to newly burnt grassland to forage for new vegetation (for kangroos) and small lizards and insects (for bustard) (see also Lundie-Jenkins, 1993, which shows that rufous hare-wallaby (*Lagorchestes hirsutus*) are attracted to burnt areas). While bustard are generally shot on the ground, they are prone to flight with any indication of people, more so when there is little vegetation cover, as in a new burn. Thus, while bustard may be sighted more often after a burn, they may be less likely to be captured. The same may also be the case for kangaroos, which tend to avoid any open spaces during most of the day, and capturing them in a burn is very difficult. In much of the Martu landscape getting close enough for a clear shot at a kangaroo usually requires stealth that is inhibited by searching in a new burn. Others have commented on the use of fire for driving and flushing game (Gould, 1971; Kimber, 1983), and it may have been more common in the past among the Martu, but we only observed this on only four of the 252 focal follows analyzed here, and in each case it involved the pursuit of feral cat. While skill and ecological knowledge were astounding, burning during gun hunts did not generally take on systematic and coordinated efforts.

This differs from *wana* hunting for burrowed game during *Wantajarra*: women who hunt burrowed game have strong incentives to control moderate and repeated burns in order to immediately increase the probability of encountering game tracks and dens. As many Martu women reported, a *wana* hunt in a very large burn can be difficult to manage. Each burn (*nyurnma*) is "owned" by the individual(s) that fired it, and rights of access to the resources within that burn at least *for that day* are exclusive. Usually women search a *nyurnma* alone, often out of eyesight of other hunters, but they sometimes signal to others once an animal or den is sighted and cooperate in pursuit. Since prey in a *nyurnma* are dispersed and encountered singly, especially large *nyurnma* make it difficult to know whether or not other hunters have already searched the area. Hunters keep a close eye out for other people's footprints in their *nyurnma*, and disputes can arise if too many hunters are thought to be too close together. Women's cooperation while hunting burrowed game is often designed for reducing this type of overlap: well-managed, moderate burns greatly facilitate this and immediately increase hunting efficiency.

The Issue of Land Management

Our study was not specifically designed to test the more general hypothesis that burning is a land management strategy that "a) prevents or mitigates resource depletion, species extirpation, or habitat degradation, and b) is designed to do so" (Smith and Wishnie, 2000, p. 501; see also Alvard, 1998a, b). However, recent research in behavioral ecology has demonstrated fundamental problems with the idea that small-scale societies often design subsistence strategies to increase long-term resource availability or stability, even if they have such effects (e.g., Alvard, 1994; 1998a, 1998b; FitzGibbon, 1998; Ruttan, 1998; Ruttan and Borgerhoff Mulder, 1999; Stearman, 1994; see reviews in Low, 1996; Smith and Wishnie, 2000). Alvard (1998b), Hawkes (1992), and Smith and Wishnie (2000) have shown that the maintenance of this type of long-term land management can be sustained only when the problems of collective action and future discounting are negligible. Collective action problems arise when the costs of providing goods are distributed individually, but the benefits of those goods can be shared by all regardless of whether or not they pay (Elster, 1983; Hardin, 1982; Olson, 1965; Ostrom, 1990; for recent anthropological treatments see Ruttan, 1998; Ruttan and Borgerhoff Mulder, 1999). Also, future benefits are necessarily discounted relative to their current value: delays in consumption decrease the chance that those benefits can be realized (Hawkes, 1992; Taylor, 1987). Future discounting among humans has been widely documented by behavioral ecologists, psychologists, and economists (see Tucker, 2005, for review).

If people design their burning practices as a strategy for long-term land management, we will need to account for future discounting and collective action problems. Engineering and managing massive landscapes with controlled fire is costly for the individuals involved, but the future benefits from these efforts can be enjoyed by many that did not pay the initial costs (e.g., Russell-Smith *et al.*, 1997a). Also, firing is initially destructive, incorporating the immediate loss of time and at least some potential resources—most researchers have generally assumed that such costs are recouped in the future with increased availability of game and plant foods (e.g., Yibarbuk *et al.*, 2001). Because burning is often associated with increasing immediate hunting returns, there is the possibility that it is not designed to be a land management strategy at all, but rather, the long-term effects are only incidental.

However, there is some circumstantial evidence to suggest that certain aspects of Martu burning are indeed designed to be a resource management strategy. First, we only measured the long-term benefits gained from hunting: many collected plant foods have very high energetic return rates (especially *Solanum* spp.), and these rates should peak one to two years after an area has been burned. Thus, while hunters may see a small benefit immediately, they may see a larger benefit in the future. But how do individuals solve the future discounting problem created by a rather open-access land tenure system that allows those that didn't burn an area access to that managed landscape? It is possible that the immediate economic incentives provided to *wana* hunters serve to eliminate the collective action problem: free-riding non-burners simply may not be able to find enough burned area to hunt when burns are small and hunters are able to search them entirely. But are there enough incentives for men to burn? It is likely that men may indirectly receive economic incentives to burn in order to increase women's foraging productivity, on which they greatly depend. However, for men especially, burning may provide more social than economic capital: it can be a signal and index of land ownership, an aesthetic interpretation of homeland, and an expression of ritual linking events of the past and future (Bradley, 1994; Bright, 1994; Dayani *et al.*, 2002; Gould, 1971; Rose, 1994, 1995; Yibarbuk *et al.*, 2001).

Secondly, while older, burnable landscapes seem to be "open-access," newly burned areas are not. Martu hunters face sanctions against entering a newly burned area without permission of the person who set the fire. A woman who "jumps into" the burn and removes the prey before the burner is likely to provoke an altercation or worse. Anthropologists currently know very little about how successional age in vegetation influences "ownership" over an area. It certainly seems likely that the need to ask permission from the fire-starter to enter the patch declines over time, but whether it declines prior to the critical one-to-two year age when fruits and seeds reach their peak production is currently unknown. Foragers entering these areas do remark that "so and so" set the fire here, but we do not know whether those "owners" retain the right to grant access to the food available within.

Even if burning was designed to be a land management strategy in the past, it may not currently function as it was designed because environments and foraging methods have changed. In particular, analysis of the effect of contemporary burning on the maintenance of wildlife diversity can be complicated by the introduction of nonindigenous species. In many locales throughout Australia a wide range of introduced mammals (rabbits, sheep, goats, cattle, donkeys, horses, camels, cats, and foxes) are thought to have caused local extinctions and severe declines of indigenous mammals (e.g., Morton, 1990; Short and Turner, 1994). No data exist on mammalian populations in the northern part of the Western Desert prior to the 1960s, but numerous Martu have indicated that many small to medium-sized marsupials were common before the exodus from the desert, but are now very rare. Whether this is a result of introduced fauna or changes in burning regimes is not known. In Martu territory, foxes are occasionally seen but do not have a viable population (males in the Western Desert are usually sterile north of 22–23 degrees S. latitude); there are no cattle, goats, or sheep, and donkeys and rabbits are very rare. Feral cats are common, but many Mardu have told us that they were present and were hunted many years prior to the local collapse of marsupial populations. However, camels must be having an effect on Martu subsistence and ecology: Martu claim that a decrease in kangaroo populations in the desert is a result of increased competition with camels for surface water. Based on this and the evidence of extreme changes in fire ecology in the Western Desert following Aboriginal exodus (Burrows *et al.*, 2000), we hypothesize that anthropogenic fire was an important factor maintaining small-medium sized marsupial populations (sensu Bolton and Latz, 1978; Burbidge and McKenzie, 1989), and that this was primarily a *consequence* of short-term hunting goals operationalized by burning. Major declines seem to be coincident with the exodus of people from the heart of the desert, not with the introduction of nonindigenous species.

Investigating the hypothesis that burning is or was a long-term land management strategy will require evaluating a host of ecological relationships far beyond the scope of our current analysis. To detect long-term effects on foraging efficiency with variability in habitat mosaic, whether other aspects of foraging success are increased through burning, and whether fine-grained habitats are a consequence or cause of variability in burning practices, will require detailed analysis of hunting and gathering over an entire yearly cycle and mapping specific burn patterns and vegetation mosaics through remote sensing and GIS technologies. Such data will greatly assist investigations of the biotic effects of historic changes in Aboriginal burning and hunting practices, and provide a baseline for cooperative and effective land management strategies in the Western Desert.

The Issue of Policy Development

This study should add to a growing appreciation of the problems involved in attempting to distinguish between "natural" and "artificial" landscapes, or that somehow we might find a strategy for the optimal treatment of pristine environments (e.g., Anderson and Berglund, 2002; Press, 1994). For all intents and purposes, Australian "wilderness" is (and in some cases has been for about 45,000 years) a product of a dynamic relationship between people and the physical environment. Or as the Martu might put it, "we are all the environment." Bowman (1998, p. 404) recently remarked (in reference to Jones' 1969 classic article on firestick farming) that there must be "a profound realization that... land managers must choose what sort of 'natural' landscapes they want, given the backdrop of an extraordinarily long period of Aboriginal burning." Of course, what kind of landscape we want is a matter of cultural practice and belief, aesthetics, politics, economics, and problems of collective action; it is not a matter of wanting to or being able to restore some pristine ideal. Nevertheless, as many Martu have remarked, a "Martu landscape" (people living at very low population densities with relatively high mobility) may be something very different from an environment that today consists of permanent Martu communities, massive mining initiatives, and increasing tourism. Not that the Martu are absolutely opposed to these, but efforts to retain a significant measure of control over *their* environment will continue within the community. This control is inextricably tied to burning.

We agree with Bowman (1998) that research for developing fire policy needs to focus on a systematic analysis of Aboriginal burning practices to inform and buttress land management prescriptions. Effective fire and land management in this region of the Western Desert will fail along most fronts without incorporating Martu participation and objectives. This will require a broad anthropological and ecological approach, building from *within* communities and taking into consideration different levels of cultural meaning, temporal and spatial ecological variability, individual conflicts of interest, and tradeoffs associated with different goals—all of which influence burning strategies and their consequences. The Martu data show that even within a single community, different people face different (and not necessarily complementary) tradeoffs relative to their subsistence and burning purposes. If Martu burning is a land management strategy, it does not appear to be designed to enhance men's kangaroo hunting, but rather to promote the productivity of key small animal and plant species. And certainly while many aspects of burning may be designed for land management, other goals also influence the frequency and extent of human-initiated fire. Thus, incorporating both women's hunting goals and men's social and religious priorities into fire policy will be critical for current conservation efforts in the Western Desert. This is more than necessary for developing operative policy: it will provide an opportunity for cooperation between land management agencies and remote Aboriginal communities that retain the skills and knowledge associated with burning and subsistence.

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