Current Evidence for Self-Medication in Primates: A Multidisciplinary Perspective

MICHAEL A. HUFFMAN
Primate Research Institute, Kyoto University, Aichi, Japan

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ABSTRACT   The study of self-medication in non-human primates sheds new light on the complex interactions of animal, plant and parasite. A variety of non-nutritional plant secondary compounds and nutrient-poor bark is found in the primate diet, but little is yet known about the possible medicinal consequences of their ingestion. Recent studies of the African great apes support a hypothesis in progress that the non-nutritional ingestion of certain plant species aid in the control of parasite infection and provide relief from related gastrointestinal upsets. Detailed behavioral, pharmacological and parasitological investigations of two such behaviors, bitter pith chewing and leaf swallowing, have been conducted on three East African chimpanzee populations, but they are now known to occur widely among all chimpanzee subspecies, as well as bonobos and lowland gorillas. For both bitter pith chewing and leaf swallowing, selection of the same plant species tends to occur among neighboring groups of same ape species. These local cultural traditions of plant selection may be transmitted when females of the same species transfer into non-natal groups. However, selection of the same plant species or species of related plant genera by two sympatric ape species or between regional populations of great ape subspecies strongly suggests a common criteria of medicinal plant selection. This and the intriguing observation that the same medicinal plant is selected by apes and humans with similar illnesses provide insight into the evolution of medicinal behavior in modern humans and the possible nature of self-medication in early hominids. The occurrence of these and other specific self-medicative behaviors, such as fur rubbing and geophagy, in primates and other animal taxa suggest the existence of an underlying mechanism for the recognition and use of plants and soils with common medicinal or functional properties. Yrbk Phys Anthropol 40:171–200, 1997.   © 1997 Wiley-Liss, Inc.

In recent years a growing body of evidence has given a burst of momentum to the study of self-medication in animals, often called 'zoopharmacognosy' (Glander, 1994; Huffman and Wrangham, 1994; Rodriguez and Wrangham, 1993). The basic premise of zoopharmacognosy is that animals utilize plant secondary compounds or other non-nutritional substances to medicate themselves.

Among primatologists a major focus of concern about plant secondary compounds in the diet has been on how and why primates can cope with their presence (Glander, 1975, 1982; Hladik, 1977a,b; Janzen, 1978; McKey, 1978; Milton, 1979; Oates, 1977; Oates et al., 1977, 1980; Wrangham and Waterman, 1981). An extreme case in point is the golden bamboo lemur (*Hapale-*

Correspondence to: Michael A. Huffman, Section of Ecology, Primate Research Institute, Kyoto University, Kanrin, Inuyama, Aichi 484 Japan. E-mail: huffman@pri.kyoto-u.ac.jp

mur aureus) of Madagascar, which is noted to consume over 12 times the lethal adult lemur dose of cyanide in a day, without ill affect (Glander et al., 1989). The cyanide comes from the tips of a bamboo species, *Cephalostachyum* sp. (Gramineae), consumed as part of the lemurs' daily diet at certain times of the year (Glander et al., 1989). In this case, the cyanide is thought to be detoxified mostly in the liver (Westly, 1980). Herbivores are able to detoxify a number of different compounds but their presence in sought after plants does have a significant effect on feeding strategies (cf. Freeland and Janzen, 1974).

One of the challenges and difficulties of interpreting self-medication is distinguishing between possible indirect medicinal benefits derived from secondary compound rich plants that are assumed to be ingested for their nutritional value vs. limited and situation specific ingestion of items that are processed solely for their medicinal properties. Even in traditional human societies, the difference between food and medicine may not always be so clear. This is exemplified by a Japanese saying "ishoku dougen"— 医食同源—which directly translated means "medicine and food are of the same origin." A case in point is the fact that some of the more traditional spices and condiments of daily Asian cuisine, such as marine algae, ginger root and herbs, contain important sources of anti-tumor agents (Murakami et al., 1994, 1996; Ohigashi et al., 1992) which may also play an important role in suppressing viral and parasite infections.

Parasites can cause a variety of diseases which affect the overall behavior and reproductive fitness of an individual (e.g. Hart, 1990; Holmes and Zohar, 1990). Therefore the need to counteract such pressure should be great (cf. Allison, 1982; Toft et al., 1991). The effects of parasitosis on the host and the host's response to infection is undoubtedly the product of a long evolutionary process (cf. Anderson and May, 1982; Barnard and Behnke, 1990; Behnke, 1987; Brooks and McLennan, 1993; Ewald, 1994; Futuyma and Slatkin, 1983; Hamilton, 1964a,b; Hamilton and Zuk, 1982; Price, 1980). Janzen (1978) first suggested the possibility that the incidental ingestion of secondary plant compounds by non-human primates and other animals may help to combat parasites.

Recent evidence from the African great apes, however, suggests that certain plants are ingested, not incidentally, but directly for their significant medicinal value. These observations provide the clearest evidence for self-medication thus far. Perhaps due to our phylogenetic closeness, humans and chimpanzees even select some of the same plants when displaying similar symptoms of illness (Huffman et al., 1996a). Unquestionably, these implications of self-medicative behavior are of extreme interest when considering the evolution of medicinal habits from the great apes to early hominids and modern humans. The hypothesis currently being developed from these investigations is that the behaviors aid in the control of intestinal parasites and/or provide relief from related gastrointestinal upset.

The evidence for self-medication by African great apes includes the infrequent intake of plant species which are not a regular part of the diet (Huffman and Seifu, 1989; Wrangham and Nishida, 1983; Wrangham and Goodall, 1989), a habit of ingestion which provides no nutritional benefit (Wrangham and Nishida, 1983; Huffman and Seifu, 1989), restriction of plant use to seasons or other periods associated with high risk of parasitic infection (Huffman et al., 1990, 1997; Kawabata and Nishida, 1991; Wrangham, 1995), illness or parasite infection of the individual at the time of ingestion of a putative medicinal plant (Huffman and Seifu, 1989; Huffman et al., 1997; Wrangham, 1995), and a subsequent positive change in this condition following ingestion (Huffman et al., 1993, 1996b).

The amount of detailed information on self-medication gathered thus far is greatest for the African great apes; however, self-medication is expected to occur in other non-human primates and other mammalian species. The purpose of this paper is to review the current range of evidence for possible indirect and direct self-medication in the African great apes and other non-human primates. Suggestive evidence of similar self-medicative behaviors in other mammalian species will be discussed to underline the important adaptive significance of these behaviors. Finally, basic guide-

lines for future research, predictions for the future and practical application of this knowledge will be discussed.

FOOD AS MEDICINE

The gap between 'medicine' and 'food' in primates may often seem transparent. Much of what is consumed no doubt contains an array of secondary compound(s). However, Johns (1990) argues that the herbal medicines and modern pharmaceuticals used by humans today have replaced the non-nutritive chemicals commonly present in animal diets. In this light, the non-nutritive components of a number of items ingested by African great apes are worth mentioning here. Their possible medicinal contribution has received little attention in the past.

Secondary compounds in fruits and leaves

Secondary compounds as well as inorganic materials are usually considered to be a plant's front line defense against all but the most specialized herbivores (Ehrlich and Raven, 1964; Feeny, 1976; Howe and Westley, 1988). These products are directly toxic to the consumer or deter consumption by reducing palatability or digestibility (Howe and Westly, 1988; Wink et al., 1993), yet a number of items under this category can be found in the great ape diet.

The berries of *Phytolacca dodecandra* L Herit (Phytolaccaceae) are an abundant and frequently ingested food item of the Kanyawara group in Kibale (Wrangham and Isabirye-Basuta, in Huffman and Wrangham, 1994). These bitter tasting berries are a concentrated source of at least four toxic triterpenoid saponins (lemmatoxin, lemmatoxin-C, oleanoglycotoxin-A, phytolacca-dodecandra glycoside), and ingestion of about 2 g of them by mice and rats is fatal. Found in the highest concentration in the berry, these compounds are now being developed in the United States to control the level of schistosome carrying snails (Abbiw, 1990; Kloos and McCullough, 1987). Other known properties of these triterpinoid saponins include antiviral, antibacterial, antifertility, spermicidal and embryotoxic activities (Kloos and McCullough, 1987). See Table 1 for other effects of common plant secondary compounds.

TABLE 1. *Some common plant secondary compounds and their effects on animals*

Class of compounds	Effects (comments)
Terpenoid alkaloids	Modulation of ion channels (highly toxic)
Isoquinoline alkaloids	DNA intercalation, interaction with receptors, causes spasms (toxic and bitter)
Quinolizidine alkaloids	Binding to ACH receptor (toxic and bitter)
Tropane alkaloids	Inhibition of ACH receptor (highly toxic)
Pyrrolizidine alkaloids	Mutagenic & carcinogenic (liver toxic)
Cyanogenic glycosides	Inhibition of respiration
Cardiac glycosides	Inhibition of Na^+/K^+-ATPase (highly toxic)
Terpenes	Diuretic (bitter taste)
Volatile terpenes	Antibiotic, irritant
Volatile monoterpenes	Antibiotic (aromatic smell)
Saponines, amines	Detergent for biomembranes (bitter)
Triterpene saponines	Detergent for biomembranes (toxic, emetic)
Sesquiterpenes, pyrrolizidines	PA are mutagenic & carcinogenic, irritant (cytotoxic, liver toxic)
Convallatoxin	Inhibition of Na^+/K^+-ATPase (highly toxic and bitter)
Anthraquinones	Purgative (toxic)
Phenolics	Astringency, reduces digestibility
Cellulose, hemicellulose, lignins, silica	Undigestible

Prepared after Wink et al., 1993; Howe and Westley, 1988.

Pith and fruit of *Afromomum* species (wild ginger family) are commonly ingested by chimpanzees, bonobos and gorillas across Africa (cf. Idani et al., 1994; Moutsamboté et al., 1994; Nishida and Uehara, 1983; Sugiyama and Koman, 1992; Tutin et al., 1994; Wrangham, 1977; Wrangham et al., 1993; Yumoto et al., 1994). A study in progress of the chemical ecology of Bwindi gorilla (*Gorilla gorilla beringei?;* see Sarmiento et al., 1996) diet by John Berry (Rodriquez Laboratory, Division of Biological Sciences, Cornell University) is investigating the bioactivity of the fruit of one of these wild ginger species, *Afromomum sanguineum* (K. Schum.) K. Schum. (Zingiberaceae). The fruits of this species, in particular, are also known to be ingested by gorillas at Kahuzi-Biega (Yumoto et al., 1994). Assays of homogenized fruit and seed extracts show significant antimicrobial activity (Berry, in preparation). The fruits are sold locally in market stalls and along the road in the Bwindi area for the treatment of bacterial and fungal infection and as an anthelmintic (Berry, personal communication).

The tips of the young leaves of *Thomandersia laurifolia* (T. Anders. ex Benth.) Baill. (Acanthaceae) are on rare occasion chewed by western lowland gorillas (*G. g. gorilla*) in the Ndoki forest of northern Congo (Kuroda, Mokumu, Nishihara, in preparation). According to Kuroda and colleagues, the local human inhabitants use these leaves as a treatment for parasites and fever. Weak antischistosomal activity has also been found from crude leaf extracts (Ohigashi, 1995).

Nutrient-poor bark and wood

Bark and wood are characteristically highly fibrous, heavily lignified, sometimes toxic, relatively indigestible and nutrient poor (Waterman, 1984). Chimpanzees and gorillas are known to infrequently ingest the bark and wood of several plant species (e.g. Huffman and Wrangham, 1994).

While the list of plant species whose bark is ingested is long, little is actually known about the contribution of bark to the diet and general health. The literature on African ethnomedicine warrants mention of a few of these species. The bark of *Pycnanthus angolensis* (Welw.) Warb. (Myristicaceae) ingested by chimpanzees at Mahale is used by West Africans as a purgative, laxative, digestive tonic, emetic and reliever of toothaches (Abbiw, 1990). Bark strips of *Grewia platyclada* K. Schum (Tiliaceae) are sometimes chewed for the relief of stomach aches by local residents at Mahale (Huffman, unpublished data, MS Kalunde, personal communication about human uses). In 1992 one juvenile male suffering from diarrhea was observed chewing and swallowing, but not ingesting fibers, of the bark of this species at Mahale (Huffman, unpublished data). Gombe chimpanzees occasionally eat the bark of *Entada abyssinica* Steud. ex A. Rich. (Mimosaceae). In Ghana, the bark is used for diarrhea and as an emetic (Abbiw, 1990). The bark of *Erythrina abyssinica* DC. (Papilionacea) is occasionally eaten by Mahale chimpanzees. Significant plasmodicidal and antischistosomal activities have been demonstrated from the bark of this species collected at Mahale (Ohigashi, 1995; Wright et al., 1993). The bark of *Gongronema latifolium* Benth. (Asclepiadaceae) occasionally eaten by Bossou chimpanzees is extremely bitter, and the stems are used in West Africa as a purge for colic, stomach pains and symptoms connected with intestinal parasite infection (Burkill, 1985).

The preceeding accounts of the ingestion of peculiar fruit, leaf, bark, and wood items serve to demonstrate the diversity of secondary compounds or inferred pharmacological activity present in great ape diets. It is also possible that some of these examples, like *T. laurifolia,* are indeed new cases of self-medication, but have remained obscure for lack of detailed behavioral and health related data. The total effect of ingesting these items is not clear, but it is too early to assume only nutritional gain.

Geophagy

Clay contains none of the essential components of nutrition; protein, carbohydrates, lipids, and vitamins. Clay soils are fine grained mineral deposits consisting mainly of the hydrous silicates of aluminum magnesium and or iron. The chief groups of clay minerals are kaolinite, halloysite, illite, montmorillonite, and vermiculie whose outstanding property is the capacity for holding water.

Geophagy is commonly practiced by many animal species and humans world-wide (e.g., Halstead, 1968; Johns, 1990; Kreulen and Jager, 1984). From the ethnographic literature, clay is consumed for its effectiveness as an anti-diarrheal and is useful for the elimination of bitter taste, prevention of stomach aches or vomiting after the consumption of large quantities of 'famine foods' high in secondary compounds (Johns, 1990). In non-human primates it has been described similarly as functioning to absorb tannins and other toxins acquired from a diet rich in secondary compounds (Davies and Baillie, 1988; Hladik, 1977a,b; Müller et al., 1997; Oates, 1978). Overconsumption of clay however can lead to serious nutritional deficiencies and illness (cf. Halstead, 1968; Kreulen, 1985).

William Mahaney and colleagues associated with the Geophagy Research Project at York University (Toronto, Ontario) have begun extensive studies in Africa (Rwanda, Uganda, Tanzania, Guinea), Asia (Sumatra, Borneo, Japan) and the Americas (Puerto Rico) to analyze soils ingested by primates and cattle. Thus far, evidence from joint

TABLE 2. Habitat description of African great ape study sites with documented or suspected medicinal plant use

Location, site name[1]	Species[2]	Altitude range	Approximate location	Vegetation type	Average annual rainfall
Eastern Africa					
Tanzania					
Mahale	*Pts*	773–2,515 m	6°07′S/29°44′E	Deciduous, evergreen gallery forest, Miombo woodland	1,836 mm
Gombe	*Pts*	773–1,500 m	4°40′S/29°38′E	Deciduous dry and evergreen riverine forest, Miombo woodland, grassland	1,600 mm
Uganda					
Bwindi	*Gg*?	1,160–2,600 m	1°S/20°35′E	Moist lower to upper montain forest, bamboo, alpine on a gradient	1,440 mm
Kibale	*Pts*	1,390–1,625 m	0°34′N/30°22′E	Medium altitude moist evergreen forest, forest-grassland, swamp	1,671 mm
Budongo	*Pts*	1,050–1,200 m	1°45′N/31°20′E	Secondary mixed forest, swamp forest, wooded grassland; selective logging	1,600 mm
Zaire					
Kahuzi-Biega	*Pts, Ggg*	600–3,308 m	2°S/28°E	Primary, secondary, swamp forest, bamboo, sub-alpine	1,800 mm
Central Africa					
Zaire					
Wamba	*Pp*	370–430 m	00°11′N/22°28′E	Rainforest-derived mosaic of dry swamp, secondary forest	2,000 mm
Congo					
Ndoki	*Ptt, Ggg*	300–400 m	2°25′N/16°35′E	Seasonal rain forest, semi-deciduous, evergreen, swamp forest, swamp clearing	1,540 mm
Western Africa					
Ivory Coast					
Tai	*Ptv*	160–245 m	5°52′N/7°20′W	Evergreen moist forest	1,829 mm
Guinea					
Bossou	*Ptv*	500–700 m	7°39′N/8°30′W	Primary and secondary forest, savana, cultivation	2,500 mm
Nimba	*Ptv*	400–1,752 m	7°32′N/8°28′W	Primary forest, cultivation	?

[1] Source: McGrew et al., 1996, all sites except for Synnott, 1985 (Budongo); Sayer et al. 1992; Sarmiento et al., 1996 (Bwindi).
[2] *Pts: Pan troglodytes schweinfurthii; Ptv: P.t. verus; Pp: Pan paniscus; Gg*?: *Gorilla gorilla* ?; *Ggg: G.g. graueri.*

geochemical and behavioral ecology studies of the mountain gorilla and rhesus monkey suggests that they may ingest soil for rare minerals of possible nutritional value or to relieve diarrhea caused by dietary changes (Mahaney et al., 1990, 1995a,b, 1996, 1997). All clay soils analyzed thus far have been shown to have components closely resembling those of Kaopectate, a pharmaceutical commercially sold to treat gastrointestinal upset and other intestinal ailments (Mahaney et al., 1990, 1995a,b, 1996, 1997).

SELF-MEDICATIVE BEHAVIOR TYPES

Among the African great apes, one or both of two proposed types of self-medicative behaviors, bitter pith chewing and leaf swallowing, have been documented from 10 sites (Table 2; Fig. 1). The majority of the details discussed below for these behaviors come from three study sites, Mahale (M group, now extinct K group), Gombe (Kasakela,

now extinct Kahama), and Kibale (Kanywara, Ngogo). However, the geographical, ecological and climatic variation of these sites listed in Table 2 is great, ranging from lower moist tropical forest and woodland to montane forest located across the entire distribution of the great apes in Africa. The great variation in geography, ecology and climate where leaf-swallowing and bitter pith chewing is known to occur suggests the possibility of their wider occurrence elsewhere. The known distribution of bitter pith chewing and leaf swallowing and geophagy within the habitat of great apes is predicted to grow as more attention is paid to them in the future.

Bitter pith chewing

Hypothesis. Bitter pith chewing is currently proposed to aid in the control of intestinal nematode infection, via pharmaco-
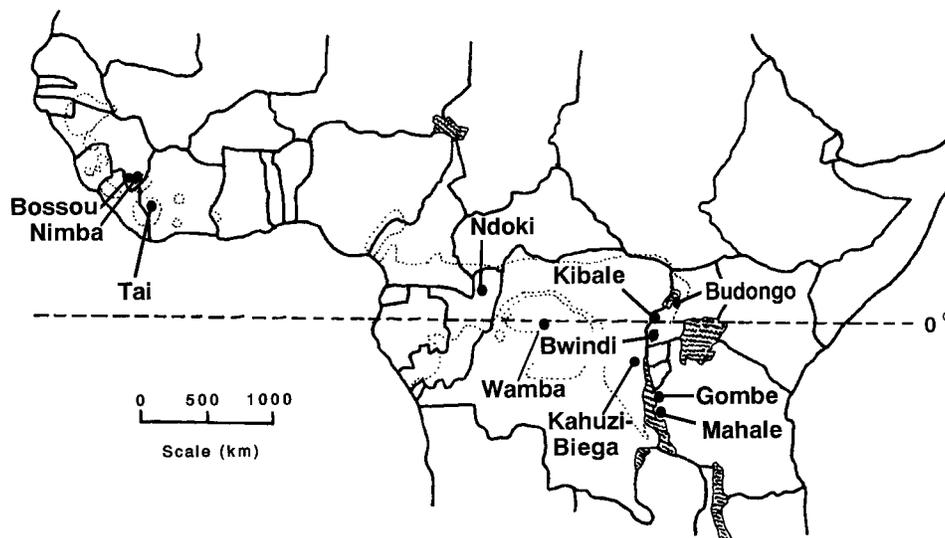
Fig. 1.   African ape study sites with documented or suspected self-medication.

logical action, and relief from gastrointestinal upset. A description of bitter pith chewing and evidence for and against this hypothesis is discussed.

Behavioral ecology.   The hypothesis that bitter pith chewing has medicinal value for chimpanzees was first proposed from detailed behavioral observations, and parasitological and phytochemical analyses of patently ill chimpanzees' ingesting *Vernonia amygdalina Del. (Compositae)* at Mahale (Huffman and Seifu, 1989; Huffman et al., 1993). These are the first reported observations to verify illness and apparent improvement thereafter of an animal ingesting putative medicinal plants. Bitter pith chewing of other *Vernonia* species has been observed at Gombe (*V. colorata* (Willde.) Drake: Wrangham, 1975; Hilali, unpublished data as personal communication from J. Wallis) and Kahuzi-Biega (*V. hochstetteri* Schi-Bip., *V. kirungae* Rob. E. Fries: Yumoto et al., 1994; A.K. Basabose, personal communication). At Tai, the bitter piths of *Paliosota hirsuta* (Thunb.) K. Schum. (Commelinacea) and *Eremospath macrocarpa* (Mann & Wendl.) Wendl. (Palmae) are chewed (C. Boesch, personal communication). However, no details are available about the state of health

of individuals observed ingesting these species (Table 2).

V. amygdalina occurs throughout tropical sub-Saharan Africa from as far north as Ethiopia, Sudan, Guinea and Mali down to Zimbabwe and Angola in the south (Burkill, 1985; Dalziel, 1937; Watt and Breyer-Brandwijk, 1962). Within the home range of M group, this species is neither abundant nor evenly distributed and usually occurs singly along or near streams. Use by chimpanzees of this plant often requires a detour from the group's travel route. When ingesting the pith from young shoots of *V. amygdalina,* chimpanzees meticulously remove the outer bark and leaves to chew on the exposed pith, from which they extract the extremely bitter juice and residual amounts of fiber (Fig. 2). The amount of pith ingested in a single bout is relatively small, ranging from portions of 5 to 120 cm $\times$ 1 cm (mean 54.57 cm, SD 41.01, n = 7). The entire process, depending on the amount ingested, takes anywhere from less than 1 to 8 minutes (mean 2.9 minutes, SD 2.59, n = 16, Uehara, Huffman, unpublished data). Mature conspecifics in proximity to an individual chewing *Vernonia* bitter pith or leaf swallowing show no interest in ingesting the pith (Huffman

Fig. 2. Bitter pith chewing of *Vernonia amygdalina* (top) and leaf swallowing (bottom) of *Aspilia mossambicensis.*

and Seifu, 1989; Huffman et al., 1997). Infants of ill mothers, however, have been observed on occasion to taste the pith discarded by their ill mothers. In one instance, an appearently healthy mother prevented her infant son from picking up a piece of *Vernonia* pith discarded by an adult male who had just left. When the infant went over to investigate, his mother put her foot on the pith and carried him away from it.

The ingestion of leaves or bark, the most abundant parts of the plant available for consumption by chimpanzees, is extremely rare. Since 1965, ingestion of bark or leaves have been observed one and two times respectively in K group (Uehara, personal communications) and leaves, but no bark, only once in M group since 1968. Interestingly, the observation of *V. amygdalina* leaf ingestion in M group in 1993 was by a patently ill adult male chimpanzee named Musa, from a small tree that lacked any usable fresh pith (Huffman et al., 1997, 1996b; unpublished data).

At Mahale, use of *V. amygdalina* has been recorded in all months except June and October (late dry season), demonstrating its year-round availability (Nishida and Uehara, 1983). Despite year round availability, use by chimpanzees is highly seasonal and rare. All but two of the eight cases of bitter pith chewing recorded between 1971 and 1974 occurred during the rainy season months (November and May) (Nishida and Nyundo, unpublished data). Bitter pith chewing was directly observed seven times in M group between 1985 and 1997 during a total of 728 hours of focal observation i.e., one feeding bout per 104 hours (Huffman, unpublished data). All of these cases occurred between November and February. Data collected on the 30 member K group continuously over a 24 month period between 1976 and 1978, shows a statistically significant tendency for the more frequent occurrence of bitter pith chewing during the rainy season (n = 36/38 days occurred in rainy season, z = 67.41, $P < 0.0001$; weighted for differential length in seasons; in Huffman et al., 1990). A peak in the frequency of bitter pith chewing was noted during December-January just after the onset of the rainy season (data not shown).

Interannual variation does occur. Despite plant availability, in some years bitter pith chewing is not observed. This suggests that factors other than plant abundance influence the frequency of occurrence of this behavior.

Parasite infection and general health. A longitudinal investigation of the intestinal parasite fauna of Mahale chimpanzees shows that they are infected by three parasite species from three genera of nematode, *Strongyloides fulleborni* (thread worm), *Trichuris trichiura* (whip worm), and *Oesophagostomum stephanostomum* (nodule worm); one genus of trematode, *Dicrocelium lanceatum* (lancet fluke); and four genera of protozoa, *Entamoeba coli* (amoeba), *Endolimax nana* (amoeba), *Iodamoeba buetschlii (amoeba),* and *Giardia lamblia* (amoeba which causes giardiasis) (Huffman et al., 1997). Chimpanzees were monitored individually over time to detect weekly, monthly, and yearly changes in infection levels. Among all M group chimpanzees monitored in 1991–1992 and 1993–1994, a statistically significant rainy season increase in the incidence of infection was noted only for individuals infected by nodular worms (Fisher's exact test, $P = 0.0001$, $P = 0.01$, respectively in Huffman et al., 1997). Among all three nematode species detected, nodular worm (95%, 14/15) infections were associated significantly more frequently with bitter pith chewing (n = 3) and leaf swallowing (n = 17) during the same two study periods than either whip worms (50%, n = 7) or thread worms (40%, n = 6) (Fisher's exact test for O.s.-T.t., $P = 0.0142$; O.s.-S.f., $P = 0.005$ in Huffman et al., 1997).

General observations on the state of health at the time bitter pith was chewed were available for four of the 10 cases recorded between 1987 and 1996 in M group. In all four cases, ill health was evidenced by the presence of diarrhea, malaise and nematode infection (Huffman et al., 1997). Detailed observations were available from longer focal observations in two of these cases. Recovery within 20–24 hours from a lack of appetite, malaise, and constipation or diarrhea was recognized (Huffman and Seifu, 1989; Huffman et al., 1993). In one case the eggs

TABLE 3. Plant species whose bitter piths are ingested by African great apes

	Eastern Africa			Western Africa
	Tanzania		Uganda	Ivory Coast
Family, *species*	Mahale (*Pts*)	Gombe (*Pts*)	Kahuzi-Biega (*Pts, Ggg*)	Tai (*Ptv*)
Compositae				
Vernonia amygdalina Del.	X			
V. colorata (Willde.) Drake		X		
V. hochstetteri Schi-Bip.			X, X	
V. kirungae Rob. E. Fries			X, X	
Commelinacea				
Palisota hirsuta (Thunb.) K. Schum.				X
Palmae				
Eremospatha macrocarpa (Mann & Wendl.) Wendl.				X

Reference of plant use data: Mahale, Huffman and Seifu, 1989; Gombe, Huffman and Wrangham, 1994; Kahuzi-Biega, Yumoto et al., 1994; A.K. Basabose, personal communication; Tai, C. Boesch, personal communication.
Pts, Pan troglodytes schweinfurthii; Ptv, P.t. verus; Ggg, Gorilla gorilla graueri?

per gram feces (EPG) level of a nodular worm infection could be measured and was found to have dropped from an EPG count of 130 to 15 within 20 hours. No change occurred in this individual's concurrent whip worm infection (Huffman et al., 1993). When compared to seven other individuals with nodular worm infections monitored over the same period, this was the only case in which such a dramatic drop in EPG was noted for nodular worm infections. A decrease was detected in only two of seven other individuals monitored over the same period. In one case the drop was minimal (15 EPGs). In the other case a total drop of 510 EPGs over 18 days was noted. Unfortunately, the patently ill male was absent from the group for most of this time and when he could be followed, use of *V. amygdalina* was not observed. It was impossible to determine whether he recovered on his own or attempted some form of self-medication. In the remaining cases, nodular worm EPG levels increased over time. The average increase was 69.9 EPG (SD = 84, range 5–236). The upper EPG figures of this range are biased by the extended time period of several weeks in between counts. The recognized increases in EPG levels represent the overall trend for increased reinfection by nodular worms at the beginning of the rainy season (Huffman et al., 1997).

O. stephanostomum is the most hazardous species of nodular worm found in the great apes (Brack, 1987). Repeated infection, as is expected to occur in the wild, causes significant complications including secondary bacterial infection, diarrhea, severe abdominal pain, weight loss, and weakness resulting in high mortality (Brack, 1987). Whip worm and thread worm infections usually are not serious and may go unnoticed in mild to moderate cases (Brach, 1987). The serious effects of nodular worms on the host, however, suggests that it may be an important stimulus for bitter pith chewing and other antiparasite behaviors.

Ethnomedicinal and phytochemical evidence. For numerous African ethnic groups, a concoction made from *V. amygdalina* is prescribed treatment for malarial fever, schistosomiasis, amoebic dysentery, several other intestinal parasites and stomachaches (Burkill, 1985; Dalziel, 1937; Huffman et al., 1996a; Watt and Breyer-Brandwijk, 1962).

Some of the species with bitter piths ingested by chimpanzees at Gombe, Kahuzi-Biega, and Tai (Table 3) also have a number of ethnomedicinal and pharmacological properties worth mentioning. *V. colorata* and *V. amygdalina,* very closely related species, are not distinguished from each other by traditional African healers with regard to their medicinal properties and folk classification (Burkill, 1985). Alkaloids occur in the pith, as well as flower and leaf of *V. hochstetteri* (Smolenski et al., 1974). *P. hirsuta* and *E. macrocarpa* are used in west African ethnomedicine for the treatment of upset stomachs, colic, as an antiseptic and analgesic and for venereal disease (Abbiw, 1990; Neuwinger, 1996). Moluscicidal activity has also been reported for *P. hirsuta* (Okunji and Iwu, 1988).
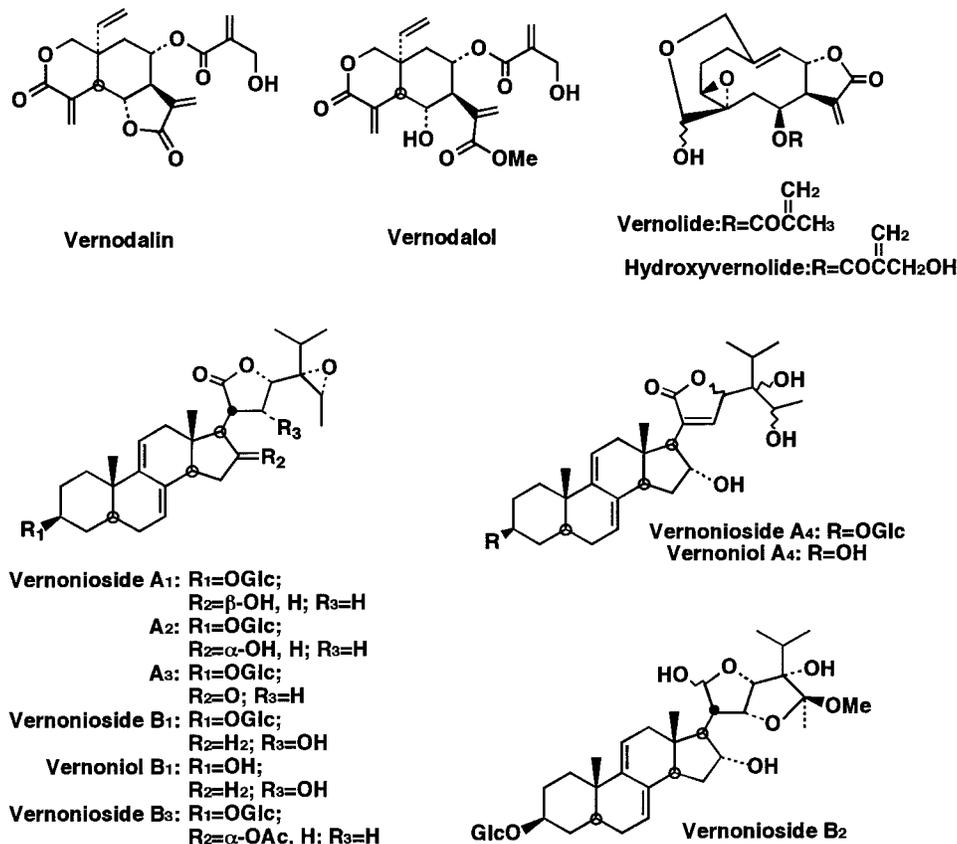
Vernodalin   **Vernodalol**   Vernolide:R=COCCH₃
Hydroxyvernolide:R=COCCH₂OH

Vernonioside A₁: R₁=OGlc;
                 R₂=β-OH, H; R₃=H
          A₂: R₁=OGlc;
                 R₂=α-OH, H; R₃=H
          A₃: R₁=OGlc;
                 R₂=O; R₃=H
Vernonioside B₁: R₁=OGlc;
                 R₂=H₂; R₃=OH
   Vernoniol B₁: R₁=OH;
                 R₂=H₂; R₃=OH
Vernonioside B₃: R₁=OGlc;
                 R₂=α-OAc, H; R₃=H

Vernonioside A₄: R=OGlc
Vernoniol A₄: R=OH

Vernonioside B₂

Fig. 3. Chemical structures of the steroid glucosides and sesquiterpene lactones isolated from *Vernonia amygdalina.*

The noted recovery time of 20–24 hours after bitter-pith chewing in two M group chimpanzees is comparable to that of local human inhabitants, the Tongwe, who use cold concoctions of this plant as a treatment for parasites, diarrhea and stomach upset. These observations encouraged Huffman and colleagues to investigate the possible contribution of plant secondary compounds in *V. amygdalina* against parasite infection. Phytochemical analysis of *V. amygdalina* samples collected at Mahale in 1989 and 1991 from plants known to be used by chimpanzees revealed the presence of two major classes of bioactive compounds (Fig. 3). From this work to date, a total of four known sesquiterpene lactones (vernodalin, vernolide, hydroxyvernolide, vernodalol), seven new stigmastane-type steroid gluco-

sides (vernonioside A_1–A_4, B_1–B_3) and two freely occurring aglycones of these glucosides (vernoniol A_1, B_1) have been isolated (Ohigashi et al., 1991; Jisaka et al., 1992a,b, 1993a,b). Figure 3 shows the newly determined chemical structures of the steroid glucosides and the widely known sesquiterpene lactones found so far in *V. amygdalina.*

Supportive of the ethnomedicinal literature, the sesquiterpene lactones present in *V. amygdalina,* also found in *V. colorata* and a number of other *Vernonia* spp., are well known for their anthelmintic, antiamoebic, antitumor, and antibiotic properties (Asaka et al., 1977; Gasquet et al., 1985; Jisaka et al., 1992a, 1993b; Kupchan et al., 1969; Toubiana and Gaudemer, 1967). From crude methanol extracts of the leaves, Koshimizu et al. (1993) also found inhibition of tumor

promotion and immunosuppressive activities.

In vitro tests on the antischistosomal activity of the pith's most abundant steroid glucoside (vernonioside B_1) and sesquiterpene lactone (vernodaline) showed significant inhibition of movement of the adult parasites and adult females' egg-laying capacity (Jisaka et al., 1992b). These findings are consistent with the observed decline in nodular worm EPG level 20 hours after an adult female chimpanzee at Mahale ingested *V. amygdalina* pith (Huffman et al., 1993).

At 200 ppm, vernonioside B_1 significantly inhibited both movement and egg-laying. At 20 ppm, however, the effects of B_1's primary (vernoniol B_1) and secondary aglycones were more active than vernonioside B_1 itself, especially against the movement of schistosomes. Similarly, the inhibition of movement activity of A_4's aglycone vernoniol A_4 was remarkably higher than that of vernonioside A_4 itself (Ohigashi et al., 1994). While these aglycones are naturally present within the pith, they are not as abundant as either vernonioside B_1 and A_4 (Jisaka et al., 1992a). However, their concentrations are thought to increase as B_1 or A_4 are metabolized into these more effective forms by hydrolysis after ingestion (Jisaka et al., 1992a; Ohigashi et al., 1994).

In vivo tests of the most active antischistosomal constituent vernodalin proved lethal to schostosome cercaria-infected mice when orally administered at 5 mg per mouse, and injected abdominally at 2 mg, or subcutaneously or intramuscularly at 5 mg, per mouse (Jisaka et al., 1992b). While abundant in the leaves and bark, this highly toxic compound occurs in only insignificant amounts in the pith. This would explain why chimpanzees normally avoid ingesting leaves and bark in preference for the pith, with its greater abundance of steroid glucosides and perhaps their aglycones (Jisaka et al., 1992a; Ohigashi et al., 1994).

In vitro tests on the antiparasitic activity of both the sesquiterpene lactones and the steroid glucosides using *Leishmania infantum* (produces visceral leishmaniasis), *Entamoeba histolytica* (produces amoebic dysentery), and a K1 multi-drug resistant strain of *Plasmodium falciparum* (produces falciparum malaria) have also been conducted (Ohigashi et al., 1994). The sesquiterpene lactones showed significant plasmodicidal activity although the IC_{50} values were more than 20 times higher than that of the common commercial agent, chloroquine diphosphate (Ohigashi et al., 1994). The steroid glucosides showed weaker plasmodicidal activity. However, as in the case described above, the activity of their aglycones was significantly higher in both plasmodicidal and amoebicidal testing. In particular, a significant increase in the plasmodicidal activity of vernoniol A_4 was noted (Ohigashi et al., 1994).

The evidence described above from parasitological, pharmacological and ethnomedicinal observations is substantial and lends support to the hypothesis that bitter pith chewing is stimulated by, and controls nematode infection. The direct evidence demonstrating a significant drop in nodule worm infection or marked improvement in health after use, however, comes from only two detailed case studies in the field. All cases obtained since then from direct observation have verified illness at the time of use, but sufficient data to reliably support or reject recovery could not be obtained. Due to the rarity of this behavior it has been extremely difficult to increase the number of cases for critical evaluation. It will be necessary to conduct controlled in vivo studies in the future on compatible animals models in order to reliably test this hypothesis further. Plans are now underway to do so (see below).

Leaf swallowing

Hypotheses. Leaf swallowing is currently proposed to control strongyle nematode infection and relieve pain caused by tapeworm infection by expelling these intestinal parasites. Both phytochemical and physical mechanisms for parasite removal have been proposed. A description of leaf swallowing behavior and evidence for and against these alternative hypotheses are discussed.

Behavioral ecology. Leaf swallowing behavior in the great apes was first recorded for chimpanzees at Gombe and Mahale (Wrangham, 1977; Wrangham and Nishida, 1983). It came to the attention of observers

at both sites that leaf swallowing was unlikely to provided any nutritional value after they found the folded, undigested leaves of *Aspilia mossambicensis* (Oliv.) (Compositae), *A. pluriseta* (O. Hoffm.) Wild, and *A. rudis* Oliv. & Hiern in the dung. The puzzling manner of ingesting *Aspilia* spp. and the suggestion that chimpanzees may possess a sophisticated pharmacopoeia (Rodriguez et al., 1985) drew the attention of other field researchers to look for similar anomalous feeding habits among apes in their study sites (e.g., Boesch, 1995; Huffman, 1993; Matsuzawa and Yamakoshi, 1996; Sugiyama and Koman, 1992; Takasaki and Hunt, 1987). As of January 1, 1997, leaf swallowing behavior involving 30 different plant species has now been observed in nine populations of chimpanzee (*Pan troglodytes schweinfurthii,* P.t. troglodytes *P.t. verus*) and in one each of bonobo (*P. paniscus*) and eastern lowland gorilla (*Gorilla gorilla graueri*) populations at 10 sites across Africa (Table 4; Fig. 1). The plant species used vary in life form (herb, vine, shrub, tree), but the common property linking all of these plants is their hairy and rough-surfaced leaves. As shown in Figure 4 from SEM photographs of the leaf surface of five representative species, trichome structure varies from long and slender (A, C, D), thorn like (B), hooked (C, not shown here but hooked hairs are a particular characteristic of *A. aequinoctiale*), and spiked (E).

The distal half of these leaves are selected one at a time, folded by tongue and palate as they are slowly pulled into the mouth and then individually swallowed whole (Fig. 2). The leaves' roughness no doubt makes them difficult to swallow, so folding them with the tongue and palate before swallowing is considered to be a necessary part of ingestion. An individual may swallow anywhere from one to 100 leaves in one bout, at a median rate of five leaves per minute (range 2.4–15.4 min., n = 7 bouts; data from Wrangham and Goodall, 1989). An individual may visit more than one bush in a day (Huffman et al., 1996b; Wrangham and Nishida, 1985).

Chimpanzees at Gombe, Mahale, Kibale and Tai are reported to swallow leaves, with clear exceptions at Mahale, early in the morning or within the first few hours after leaving their sleeping nests (Boesch, 1995; Wrangham and Goodall, 1989; Wrangham and Nishida, 1983; Huffman et al., 1996b) and thus, on a relatively empty stomach. The leaves of at least four species reported to be swallowed by apes in Table 4 (*A. mossambicensis, Trema orientalis* (L) Blume syn. *T. quineensis* (Ulmacea), *Ficus exasperata* Vahl, and *F. mucuso* Fichalho (Moraceae)) are also chewed when ingested by chimpanzees at other times (Nishida, Huffman: Mahale; Yamakoshi, Takemoto: Bossou, unpublished data). *F. exasperata* in particular is also a common food source by chimpanzees and other non-human primates at these and other study sites. This habit of chewing to ingest large amounts of the same leaf material swallowed without chewing at other times presents an intriguing dichotomy of use.

Longitudinal data on the temporal occurrence of leaf swallowing taken from both direct observations and the presence of leaves in the dung are available currently only for *Aspilia* sp. at Mahale (K group) and Gombe (Kasakela, Kahama communities), and for *A. aequinoctiale* (P. Beauve) Loudon (Commelinaceae) and *R. cordifolia* L (Rubiaceae) at Kibale (Kanyawara, Ngogo). At all of these sites, leaf swallowing is an extremely rare behavior. An average rate of once per every 69.0 hours (n = 18 bouts during 1,242 hours) and once every 81.9 hours (n = 11 bouts during 901.37 hours) for *A. mossambicensis* at Mahale and once per every 102.6 hours (n = 10 bouts during 1,026 hours) for *Aspilia* spp. at Gombe have been reported (Wrangham and Nishida, 1983; S. Uehara, unpublished data).

Aspilia leaves are available year-round at both Gombe and Mahale. Direct observation and the inspection of dung for the presence of whole leaves confirms this by showing that *Aspilia* spp. leaf swallowing has occurred in all months except April and November at Gombe, and every month at Mahale (Wrangham and Goodall, 1989; Wrangham and Nishida, 1983). Nonetheless, interannual variation in the frequency of leaf swallowing at Mahale and Gombe is substantial. At Mahale use was most common after the beginning of the rainy season (November–
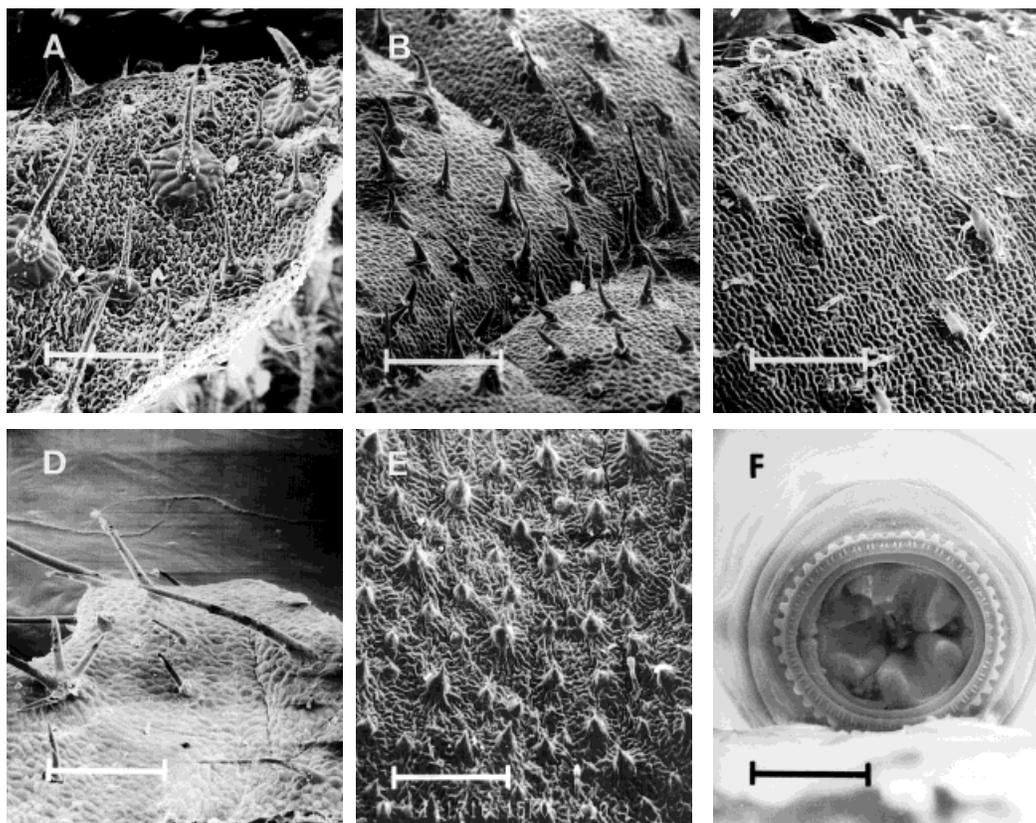
TABLE 4. Plant species swallowed whole by African great apes

| Family, species | Eastern Africa | | | | Central Africa | | | Western Africa | | |
| | Tanzania | | Uganda | | Zaire | | Congo | Ivory Coast | | Guinea |
	Mahale (Pts)	Gombe (Pts)	Kibale (Pts)	Budongo (Pts)	Kahuzi-Biega (Ggg, Pts)	Wamba (Pp)	Ndoki (Ptt)	Tai (Ptv)	Nimba (Ptv)	Bossou (Ptv)
Compositae										
Aspilia mossambicensis (Oliv.)	X									
A. pluriseta (O. Hoffm.) Wild		X								
A. rudis Oliv. and Hiern		X								
Malvaceae										
Hibiscus aponeurus Sprague and Hutch	X	X								
Verbenaceae										
Lippia plicata Baker	X									
Commelinaceae										
Commelina diffusa Burm. f.	X									
C. benghalensis Linn.	X									
C. ceciliae C.B. Clarke										
Aneilema aequinoctiale (P. Beauv.) Loudon	X		X	X	X, X					
A. nyasense C.B. Clarke	X			X						
Rubiaceae										
Rubia cordifolia L.			X							
Gramineae										
Hyparrhenia cymbaria (Linn.) Stapf			X							
Moraceae										
Ficus exasperata Vahl	X									X
F. mucuso Ficalho										X
Antiaris africana Engl.										X
Ulmaceae										
Trema orientalis (L) Blume syn. T. quineensis	X									
Celtis adorfi-frederici Engl.										X
Melastomataceae										
Melastomastrum capitatum Vahl A. and R. Fernandes	X									
Tristemma coronatum Benth.								X		
Dichaetanthera africana (Hook. f.) Jac.-Fel. l.c. (syn. Sakersia africana)								X		
Convolvulaceae										
Ipomoea involucrata P. Beauv.					X					
Cucurbitaceae										
Lagenaria abyssinica (Hook. f.) C. Jeffrey					X			X		
Adenopus abyssinicus Hook. F.					X			X		
Peponium sp.					X			X (2 spp.)		
Icacinaceae										
Polycephalium capitatum (Baill.)									X	X
Euphorbiaceae										
Maniophyton fulvum Mull. Arg						X	X			
Cyperaceae sp.										
Unidentified spp.				X (1 sp.)				X (2 spp.)		X
n = 30 spp. (incl. 3 unidentified spp.)	10	3	3	3	5	1	1	6	1	6

Source of plant use: Mahale, Huffman, 1993, Huffman et al., 1996b, 1997, Huffman and Wrangham, 1994, T. Nishidsa, H. Takasaki, M. Hamai, personal communication; Gombe, Wrangham and Nishida, 1983, Wrangham and Goodall, 1989; Kibale: Wrangham, 1995; Budongo, C. Bakuneeta, V. Reynolds, personal communication; Kahuzi-Biega, Yumoto et al., 1994, A.K. Basabose. J. Yamgiwa, personal communication; Wamba: S. Kuroda, personal communication; Ndoki: S. Kuroda, T. Nishihara, personal communication; Tai: C. Boesch, 1995 and personal communication; Nimba: Matsuzawa and Yamakoshi, 1996; Bossou: G. Yamakoshi, H. Takemoto, personal communication.
Pts, Pan troglodytes schweinfurthii; Ptt, P.t. troglodytes; Ptv, P.t. verus; Pp, P. paniscus; Ggg, Gorilla gorilla graueri.

Fig. 4.   Electron micrographs of the upper leaf surface of five species swallowed whole by chimpanzees. A: *A. mossambicensis.* B: *L. plicata.* C: *A. aequinoctale.* D: *H. aponeurus.* E: *T. orientalis* and the mouth part of the intestinal nematode. F: *O. stephanostomum* (scale bar = 500 μm). From Huffman et al. (1996b).

May) with peak frequencies in January and February being 10–12 times higher than those of other months (Wrangham and Nishida, 1983). Direct observations and dung samples collected from the Mahale K group over a continuous 24 month period, between 1976 and 1977, illustrate the tendency observed in other years for the more frequent occurrence of leaf swallowing during the rainy season. Leaf swallowing occurred on a statistically significantly greater number of days in the rainy season than in the dry season (n = 19/20 days occurred in rainy season, binomial test z = 67.41, $P < 0.0003$; weighted for differential length in seasons; unpublished data by Uehara and Nishida in Huffman et al., 1990). In Gombe peak frequencies of use were also observed in January (4 years), February (2), March and May

(2), but also once in July (Wrangham and Goodall, 1989).

At Kibale, direct observations have been made only three times, but systematic dung collection from December 1987 to May 1994 provides evidence (n = 44) for leaf swallowing in both Kanywara and Ngogo chimpanzees (Wrangham, 1995). Leaves of *A. aequinoctiale* and *R. cordifolia* are swallowed by both Kanyawara and Ngogo chimpanzees; however, the leaves of both species were found significantly more often in the dung of Kanyawara chimpanzees (*A. aequinoctiale:* Wilcoxon z = 2.97, n = 13 with nontied data from both sites, $P < 0.01$; *R. cordifolia:* z = 2.27, n = 13, $P < 0.05$; Wrangham, 1995). Leaves were found in the dung of Kanyawara chimpanzee in all months (78 months) except September, November and

December, with repeated peaks in the periods between January–February, March, April–June and July (calculated from Figure 1 of Wrangham, 1995). Unlike the distinct dry (June–October) and rainy (November–May) season pattern of Gombe and Mahale, rainfalls more evenly throughout the year at Kanyawara with two "wet periods" (approx. March–May and August–November) and two drier "transitional periods" (approx. December–February and June–July) but no extended dry season (Struhsaker, 1997). Based on this general criteria, no significant difference was detected in the frequency of leaf swallowing between the wet and transitional periods at Kanyawara (Mann-Whitney U-test, corrected for ties, $z = -.917$, $P = 0.3594$; percent of dung containing whole leaves/month was estimated by the author to the nearest whole number from Figure 1 of Wrangham, 1995).

Parasite infection and general health. Information on parasite infection and health at the time of leaf swallowing is only available from observations at Mahale and Kibale. This information varies in a number of important aspects so these two sites will be discussed separately below.

Mahale. Behavioral profiles were collected concurrently with all cases of leaf swallowing observed during a 4-month study from December 1993 to February 1994 at Mahale (Huffman et al., 1996b). As part of this procedure, dung samples were systematically inspected during focal-animal and ad libitum observations. This was done to macroscopically check for the presence of whole leaves and parasites in the dung, to monitor general health by stool type (diarrheal or normal) and to collect samples for microscopic evaluation of nematode infection levels, in the laboratory. Nematode infection was demonstrated in 83% of all cases of leaf swallowing documented (n = 10/12 cases, 11 individuals; five from dung samples; seven from direct observation, Huffman et al., 1996b). Multiple species infections were common, but nodular worm infections (78%) were most commonly associated with leaf swallowing behavior; followed by those of

thread worms (56%) and whip worms (33%). Infection by other intestinal parasite species were rare and inconsequential during this study period. As noted above, during the rainy season there is a significant trend for the increase in the number of individuals infected with nodular worms at Mahale. Thread worm infections remained low year-round and whip worm infections were inconsistent from year to year in their rainy season–dry season prevalence of infection (Huffman et al., 1997). The presence of these two nematode species may have intensified symptoms of illness, but alone their impact on chimpanzees was not found to be substantial.

Symptoms which may be caused by infections from these nematodes (diarrhea, malaise, abdominal pain; Brack, 1987; Anderson, 1992) were verified from direct observation in seven of the eight chimpanzees at the time that leaves were swallowed (Huffman et al., 1996b, 1997). Parasite worms, all later identified as nodular worms (*Oesophagostomum stephanostomum;* body, ca. 2.5 cm), were found in 3.7% (n = 9/254) of the dung collected from focal and non-focal individuals. The occurrence of worms in the dung was rare and limited to individuals that displayed symptoms of malaise and diarrhea.

Kibale. Longitudinal microscopic data for nematode infection in Kibale chimpanzees are not available. However, the most frequently occurring genera of parasites in Kibale, Gombe, Mahale and Budongo chimpanzees have been reported to be a nodular worm species (*Oesophagostomum* spp.) followed by thread worms and whip worms (Barrows, 1996; File et al., 1976; Huffman et al., 1997; Rodriguez and Wrangham, 1993). During a 78-month monitoring period of chimpanzee dung between 1987 and 1994 at Kanyawara, tapeworm proglottid fragments (*Bertiella studeri*) were found in 1% (16/1,696) of the total chimpanzee dungs inspected. This occurrence of tapeworm fragments in the dung was restricted to a 6-month period ("transitional-wet-transitional") referred to by Wrangham as the period of tapeworm infection. Note however that the absence of tapeworm fragments in

the dung does not rule out the possibility of tapeworm infection. Infection can be proceeded by as long as 2 years before proglottids of this species appear in the feces of humans (Beaver et al., 1984).

Direct observation of leaf swallowing at Kibale has only been observed three times. Parasite infection and a general evaluation of health around the time of leaf swallowing could only be inferred from macroscopic dung analysis (Wrangham, 1995). From 12 dungs containing tapeworm fragments collected during this 6 month period, three were diarrheal and another three were scored as intermediate between diarrheal and normal. From this it was suggested that some chimpanzees egesting tapeworm fragments may experience digestive disturbances, but it was not mentioned if these dungs contained leaves or not (Wrangham, 1995).

Parasites and the possible functions and mechanisms of leaf swallowing

The Mahale nodular worm hypothesis. The nematode control hypothesis derived from the Mahale leaf swallowing data complements that of bitter pith chewing in function but differs in its proposed mechanism. At Mahale both behaviors are sometimes displayed by the same individual on the same day and together may have a synergetic affect on nodular worm infection. In 1993–1994, six of the nine dungs (n = 254) found to contain worms also contained whole undigested leaves of *A. mossambicensis, T. orientalis* or *A. aequinoctiale.* The remaining three dungs containing worms but no leaves were collected from three of the individuals whose dung contained both leaves and worms earlier that day (Huffman et al., 1996b). This suggests that worms may continue to be expelled for a short while after leaves have been egested. In only one case were worms not found in the dung when leaves were present during the same study period. The relationship between the presence of both leaves and nodular worms in the dung was highly significant (Fisher's exact test, two sided, $P = 0.0001$; Huffman et al., 1996b). From this it was observed that a strong relationship between leaf swallowing and the expulsion of nodular worms existed.

A possible mechanism for nodular worm expulsion was partially deduced from the examination of three of these dung samples which contained leaves and worms. The contents of these dung were macroscopically inspected 4 days after collection, having been stored in plastic bags and kept in a cool dark room. The contents of the dung were 18 leaves:18 worms, 51:21 and 1:2 respectively. In one dung, two nodular worms were found firmly attached by the trichomes to the surface of an *A. aequinoctiale* leaf as if by Velcro. The majority of the other nodular worms were trapped within the folded leaves. All worms where alive and motile at the time of inspection.

It is unlikely that the total number of worms and leaves from one stool represents the total outcome of one leaf swallowing bout. Unfortunately it is impossible to verify the total outcome of a leaf swallowing bout in the wild because not all dungs can be collected and not all cases of leaf swallowing can be observed from an individual over the entire course of its illness. Leaf swallowing appears to affect only nodular worms. Nodular worms inhabit the large intestine, where they attach by the buccal capsule (Fig. 4). This attachment is not permanent and worms move around the intestine in search of food and mates (Anderson, 1992). Adult thread worms (2 mm) and whip worms (30–40 mm) on the other hand are smaller and burrow into the mucosa of the small intestine and caecum, respectively, where they embed themselves firmly (Anderson, 1992) and thus are not considered to be susceptible to mechanical removal by the leaves. The "control of nematode infection hypothesis" predicts that since nodular worm infections are typically self-limiting (Beaver et al., 1984), the total infection may be controllable if a chimpanzee periodically swallows leaves during the most likely period of reinfection. In general, for all nodular worm species the peak period of reinfection is the rainy season (Krepel et al., 1995). At Mahale the peak period of reinfection by the nodular worm *O. stephanostomum* was found to occur 1 to 2 months after the onset of the rainy season around December or January

(Huffman et al., 1997). This is also the time when chimpanzees tend to swallow leaves (and chew bitter pith) most frequently at Mahale and Gombe (Huffman et al., 1990, 1996b, 1997; Wrangham and Goodall, 1989; Wrangham and Nishida, 1983). The continued expulsion of adult worms over time from successive bouts of leaf swallowing may be partially responsible for the observed decline in total nodular worm egg burdens (directly correlated to the number of egg laying adults) later on in the rainy season (Figure 2 in Huffman et al., 1997).

Nodular worms produce abdominal pain along with bowel irritation and diarrhea (Brack, 1987), symptoms which could provide ample stimulus for leaf swallowing behavior in chimpanzees infected with this nematode (Huffman and Seifu, 1989; Huffman et al., 1993, 1996b).

The Kibale tapeworm hypothesis. In 1993, significantly more leaves (8.5% of 271 dungs) were found in dungs during the 6-month period of tapeworm fragment egestion than in the dungs outside of this period (1.3% of 1,425 dung collected between 1987 and 1992) (Mann-Whitney z = 4.32, $P < 0.001$; Wrangham, 1995). Also, the proportion of dungs with both tapeworm fragments and leaves (21.7% n = 23) was significantly higher than the proportion of dungs with whole leaves and no tapeworm fragments (3.6%, n = 248; Binomial test, z = 4.46, P < 0.001; Wrangham, 1995). From this Wrangham concluded that whole leaves in the gut increase the probability of tapeworms fragments being shed.

Whole leaves were found in dung during 21 months of the survey, while leaves and tapeworms were found together in only 33% of these months. It is possible that some tapeworm fragments went undetected. The greater overall occurrence of leaves in dung without tapeworms, however, suggests that the expulsion of proglottid fragments may not be the direct function of leaf swallowing. Wrangham (1995) proposes that the stimuli for leaf swallowing as observed at Kibale could be abdominal pain caused by tapeworm infections and thus leaf swallowing may function to alleviate pain. In this light, it seems likely that chimpanzees were responding to discomfort from the presence of tapeworms in the intestines before tapeworm proglottid fragments began to appear in the dung. This would explain the long period of leaf swallowing observed before proglottid expulsion.

Comparative evidence for tapeworm expulsion and leaf swallowing. Observations of undigested plant leaf material and large masses of tapeworms in the dung of Alaskan brown bears by Barrie Gilbert (Department of Fisheries and Wildlife, Utah State University) suggest some striking similarities with African apes in both mechanism and function. Gilbert observed what first appeared to him as anomalous plant ingestion in the fall months just prior to hibernation by Alaskan brown bears during a 6-year behavioral study at Brooks River in Katmai National Park, Alaska (B. Gilbert, personal communication).

During the spring in coastal regions, a brown bear's diet consists 100% of estuarine sedge (Luque and Stokes, 1976). *Carex* sp. (Cyperaceae) was the species ingested before salmon arrived. Note that an unidentified species of Cyperaceae is also swallowed whole by chimpanzees at Tai (Table 4). At this time of year sedge consumption is highly correlated with an increased phase of protein content and low structural cellulose. In the fall, however, foraging is consistently on high fat-content items, definitely eliminating sedge, which is rather inefficiently digested, even in its least woody phase of growth in spring. In the fall, *Carex* sp. is extremely high in fibre tissue, rather sharp edged and coarse. At this same time, large dung masses, almost completely composed of long tapeworms, are often observed. The tapeworms appeared to be expelled in near entirety, although worms were never examined closely enough to see if the scolex was present.

These observations lead Gilbert to question what an animal would suffer in energy loss, etc., if it went into hibernation for 6–7 months with a gut lined with tapeworms. He presumes that, as the temperature of bears is within a few degrees of normal during hibernation, gut parasites would not become particularly inactive. Bears eat prodigious

quantities of decomposed salmon, making their liquid feces rich in digestible nutrients. With the hyperphagia of bears in fall and the volume of liquid salmon in their guts, tapeworms would flourish and thus be a distinct liability during hibernation. However, parasite levels in hibernating bears are in fact quite low (Choquette et al., 1969).

What Gilbert proposes is that the coarse leaf material functions as a rasping plug or "Brillo" pad to scrape off the scolices. In effect, if a bear were to ingest coarse leaf material prior to going into hibernation, this might help to decrease its tapeworm load. This mechanical action would account for the observation of dung composed almost completely of tapeworms. Previously, the loss of tapeworms each year before hibernating and reinfection in the spring has been ascribed to a change in diet (Rausch, 1954, 1961). The above account suggests that the manner in which items of no nutritional value are ingested is of critical importance.

John Holmes (Parasitology, Department of Biological Sciences, University of Alberta) has noted a similar phenomena in Canadian snow geese. In the summer prior to their migration south, juvenile birds in particular carry significant tapeworm burdens. Also at this time of year, Holmes observed large boluses of undigested grass and tapeworms in goose dung. When the parasite loads of these same flocks were measured after migrating south, their mid-lower guts were found to be completely clean, with no scolices attached. In both of the cases mentioned above, tapeworms were shed around a time of critical nutritional stress. This too may help to clean the gut of bacteria and parasites that may be a problem during long periods of winter inactivity.

Feeding is greatly reduced or stopped entirely when these animals are hibernating or migrating. During these critical periods the cost of competition with gut parasites for a limited source of metabolites and stored energy is expected to be high. Similar purging may be applicable to ape populations, like Kibale, where tapeworm burdens are prevalent. If so, it can be predicted that the relative frequency of leaf swallowing would increase during periods of combined food stress (e.g., fruit shortage) and a high

incidence of parasite infection. This may apply to infections of both nodular worms and tapeworms. The possible correlation between periods of food stress, parasite infection and leaf swallowing needs to be investigated in the future.

Phytochemical hypotheses for chimpanzee leaf swallowing and the pharmacological evidence.   Thiarubrine A (Towers et al., 1985), a powerful antibiotic, antifungal and anthelmintic secondary plant compound was reported by Rodriguez et al. (1985) to be in the leaves of *A. mossambicensis* and *A. pluriseta.* Rodriguez and Wrangham (1993) later proposed that thiarubrine A in the leaves of *A. mossambicensis* could act as a nematocide. Two alternative hypotheses were proposed to explain the function of swallowing rather than chewing *Aspilia* leaves in the presence of thiarubrine A: "buccal absorption" (Newton and Nishida, 1990) and "unchewed leaves as thiarubrine A protective capsules" (Rodriguez and Wrangham, 1993). Both were proposed ad hoc to resolve the dilemma of how thiarubrine A would make it to the site of treatment without being destroyed by gastric acids.

However, after numerous attempts to replicate the earlier phytochemical findings Page and colleagues (1992, 1997) could detect no trace of thiarubrine A, B, D, E or their corresponding thiophenes in the leaves of 27 samples of three *Aspillia* species, *A. mossambicensis, A. rudis* and *A. africana* Pers. C.D., collected from Mahale and Gombe in Tanzania; Nanyuki Kenya; the Kampala District in Uganda, or greenhouse grown specimens from Vancouver. Furthermore, analysis of various *Aspilia* spp. leaves revealed no detectable antifungal activity against *Candida albicans* (Page et al., 1997), a human pathogenic yeast sensitive to thiarubrines (Towers et al., 1985). Messer and Wrangham (1995) also found no nematocidal activity against infective L3 stage *Strongyloides* nematode larvae in the leaf extracts of *Rubia cordifolia* L. (Compositae). These phytochemical hypotheses have been abandoned due to lack of any supportive evidence (Huffman et al., 1996b; Page et al., 1997).

The possibility has not been completely abandoned for secondary compounds in the leaves of species being swallowed to have some effect on intestinal parasites. Because of the wide taxonomic variety of plants swallowed by the African great apes a hypothesis compatible with this idea would require a common biological activity to be induced by different secondary compounds. Support for this comes from in vitro anti-schistosomal analyses of five species from five different families known to be swallowed by apes at five study sites; *Maniophyton fulvum* Mull. Arg (Euphorbiaceae), *Ipomea involucrata* P. Beauv. (Convulvulaceae), *T. orientalis, Lippia plicata* Baker (Verbenaceae) and *Lagenaria abyssinica* (Hook. f.) C. Jeffrey (Cucurbitaceae) (Table 4). All five species exhibit weak, but similar, inhibition of movement and egg-laying activity on adult schistosomes (*S. japonica*) (Ohigashi et al., in preparation). Specific compounds responsible for this action have not yet been isolated.

At present there is no direct evidence from field observations to suggest a specific role for plant secondary compounds in parasite expulsion via leaf swallowing but the following is offered as speculation for future research. One way that nematode expulsion may be chemically mediated is by decreasing a worm's ability to attach itself to the mucosal wall of the intestine, making it more prone to being "swept out" by the same rough whole leaves as they pass through the gut (Huffman et al., 1996b). A variety of compounds are known to affect parasite behavior, and chemical communication occurs between parasites via pheromones which attract and or repel conspecifics (e.g. Haseeb and Fried, 1988; MacKinnon, 1987; Salafsky et al., 1984; Sukhdeo and Sukhdeo, 1994). Some form of chemotaxis may alternatively explain why worms are attracted into the folds of the leaves before being expelled (Huffman et al., 1996b).

OTHER POSSIBLE SELF-MEDICATING BEHAVIORS

Suggestive evidence for other types of self-medication in non-human primates and in other mammalian species has been reported (see Clayton and Wolfe, 1993; Glander, 1994; Hart, 1990). In each case the evidence is variable and most often incomplete but given the wide spread occurrence of these behaviors across animal taxa they are briefly reviewed here.

Fur rubbing

Hypothesis. Fur rubbing is seen in a number of mammalian species including non-human primates. Nutritional gain can be ignored as the items used in fur rubbing are not eaten. With regards to its possible medicative function, fur rubbing has been proposed to repel insects and ectoparasites and provide topical skin treatment for fungal and bacterial infections.

Behavioral ecology. Fur rubbing is commonly observed in wild and captive capuchin monkeys (*Cebus capucinus*) and has been reported for a group of spider monkeys (*Ateles geoffroyi*) (e.g. Baker, 1996; Buckley, 1983; Oppenheimer, 1968; Richard, 1970; Ludes and Anderson, 1995). Plant material can be applied directly or chewed, and mixed with saliva, rubbed frenziedly into the fur.

Baker (1996) studied fur rubbing in capuchins on the southeastern edge of the Nicoya Peninsula of Costa Rica. Fifty-three bouts were observed during a total of 1,140 hours, i.e., one bout per 19.36 hours. Duration of time spent fur rubbing ranged from 10 seconds to 41 minutes (mean 6.3 seconds). Solitary and group rubbing was observed. Capuchins used at least five different plant genera including fruits of four introduced *Citrus* spp. (Rutaceae), the leaves and stems of *Sloanea teniflora* (Elaeocarpuseae), *Clematis dioica* L (Ranunculaceae) and *Piper marginatum* Jacq. (Piperaceae). *Citrus* (lemon, lime, orange) was the most frequently used genus, but use was often combined with other plant types.

Citrus fruits were used exclusively during the dry season; however, fur rubbing occurred more often in the rainy season (f = 0.085) than the dry season (f = 0.018). This seasonal difference was found to be significant (chi square = 15.8, $P < 0.05$; Baker, 1996). The trend for an increase in fur rubbing during the rainy season was suggested to be related to an increase in risk

to bacterial and fungal infection due to a rise in temperature and humidity.

Wild Kodiak and brown bears chew the roots of *Ligisticum porteri* (Umbelliferae) and then spread their saliva mixed with root into their fur (Siegstadt, unpublished data in Cowen, 1990). Captive bears can be induced to exhibit this behavior when presented with these *Ligisticum* roots or similar pundgent smelling material (J. Siegstadt, personal communication). Chewing of the root presumably releases its active compounds and mixes them with saliva for easy application into the fur or skin below.

White-nosed coatis (*Nasua narica*) on Barro Colorado Island, Panama, take the menthol-like smelling resin from freshly scraped bark of *Trattinnickia aspera* (Swart) (Burseraceae) and vigorously rub it into their own fur and/or that of conspecifics (Gompper and Holyman, 1993). Grooming lasts from 30 seconds to 4.5 minutes. Gompper and Holyman note that the practice of fur rubbing by white-nosed coatis using *T. aspera* also occurs elsewhere in Panama. The pharmacological activity of *T. aspera* resin used by coatis is presently unknown.

Phytochemical and ethnobotanical evidence. A number of the plant species observed by Baker (1996) to be used are known to contain secondary compounds having insecticidal, antiseptic, fungistatic, anti-inflammatory, anesthetic, and general dermatological activities. Richard (1970) suggested that the use of citrus fruits by spider monkeys might repel insects or act as an astringent. All plants share the common quality of being pungent. Fur rubbing by capuchins observed in captivity and elsewhere include the use of a variety of pungent smelling items such as tobacco, onions, garlic, millipedes, and formic acid (cf. Baker, 1996).

L. porteri, appropriately called "bear medicine" in parts of western North America, is used as a topical anesthetic and antibacterial by native Americans in the southwest. It contains volatile and fixed oils, a lactone glycoside, an alkaloid, phytosterols, saponins and ferulic acid (Moore, 1979). Navaho folklore states that revered use of the plant was taught to them by the bear (Siegstadt, unpublished data in Cowen, 1990).

Alternative non-medicinal functions for fur rubbing described above includes the facilitation of social grooming, thermal regulation, conditioning of the pelage and group scenting (Baker, 1996; Richard, 1970; Ludes and Anderson, 1995; Gompper and Holyman, 1993).

Regulation of reproduction

Hypothesis. Plant hormones are known to affect reproduction in a number of animal and insect species. Plant secondary compounds and phytoestrogen in the diet of primates are proposed to facultatively effect birth spacing, influence the sex of offspring and regulate fertility.

Behavioral ecology. Glander (1980) was probably the first to suggest a possible link between the inhibitive effect of plant secondary compounds found in key food resources and facultative birth spacing. As one possible explanation for the observed interannual variation in birth spacing of howler monkeys, he suggested that females as a whole may concentrate births seasonally in years when secondary compound concentration in plant foods are low (high food quality) and spread births out when concentrations are high (low food quality). Glander (1994) has also speculated that chemical components of their diet may allow females to select the sex of their infant. Specific plants thought to be responsible for the regulation of fertility in howler monkeys have not yet been identified.

In a 26-month study by Whitten (1983) the timing of onset, duration and ending of seasonal mating behavior in female vervet monkeys (*Cercopithecus aethiops*) was closely correlated with the availability and ingestion of the flowers of *Acacia elatior* Brenan (Mimosaceae). Later Garey et al. (1992) analyzed the flowers of this species and found them to be estrogenic. It was ascertained by Garey and colleagues that the amount of flowers consumed by vervet monkeys would provide adequate exogenous estrogen to stimulate the onset of mating activity.

An in-depth examination of sex and reproduction in the Gombe chimpanzees by Wallis (1995, 1997) noted significant seasonal pat-

terns in a number of reproductive parameters including conception, anogenital swelling, infant mortality and fertility. Diet was predicted to be a mediating factor (Wallis, 1992, 1994). In particular, phytoestrogen induced fertility regulation as a consequence of intensive foraging on seasonally available plant foods was proposed (Wallis, 1997).

Pharmacological evidence.   Phytochemical data supporting or rejecting plant based reproductive control in non-human primates are scarce. With regards to the great apes, the presence of two active diterpenes (kaurenoic and grandiflornenic acid) in *Aspilia* spp. collected from Mahale and Gombe have been reported (Huffman et al., 1996b; Page et al., 1992). Page et al. (1992) found that both compounds exhibited uterostimulatory activity on in vitro oestrogenized female guinea pig uterine tissues. Potent uterotonic activity of kaurenoic and grandiflornenic acids has also been reported elsewhere (Gallegos, 1985; Ponce-Monter et al., 1983). Page suggested that ingestion of the leaves might have a secondary effect on reproduction in female chimpanzees ingesting the leaves of *Aspilia* spp. plants. However, it is not known if the compounds are available to chimpanzees in significant amounts or whether the typical form of ingestion of *Aspilia* leaves (swallowing whole without chewing) allows for their appropriate release into the body.

A number of invertebrates, such as butterfly species of the family Lepidoptera, are dependent upon plant secondary compounds, such as pyrrolizidine alkaloid precursor in *Helioptropium* sp. (Boraginaceae), to produce sex hormones essential for reproduction (Chapman and Blaney, 1979). Plant secondary compounds found in the diet of some mammals too are suggested to either trigger or inhibit ovulation and conception (e.g. Berger et al., 1977; Starker, 1976; Sadlier, 1969). Throughout history humans have utilized a number of plant hormones to suppress and enhance their reproductive and sexual activity (Lewis and Elvin-Lewis, 1977). To date, however, detailed non-human primate studies combining both behavioral ecology and phytochemistry have not

been published. This is an extremely exciting area wide open for research.

MEDICINAL PLANT SELECTION: ORIGINS, MECHANISMS OF TRANSMISSION, AND LEARNING

The diversity of plant taxa selected by apes for possible self-medication is likely to be influenced by the ecological and geographical diversity of the habitats represented (Table 2), yet a pattern emerges from the species known to be selected by apes across Africa for bitter pith chewing and leaf swallowing. Apes of the same species in adjacent groups or regional populations tend to use many of the same or related plant species. The same or related plant species are also selected by different ape species in neighboring, regional and intra-regional populations (see Table 3, 4). This would suggest that all ape species are using a common criteria when they select plants for self-medication.

Origins of self-medicative behaviors, plant selection criteria as a product of function

The similarity of plants selected by neighboring populations of the same species may represent localized cultural traditions, maintained in part by information exchange via female group transfer (cf. Huffman and Wrangham, 1994; Matsuzawa and Yamakoshi, 1996). However, the use of one plant species by two sympatric ape species need not be explained by inter-species interactions, although the possibility of inter-species exchange of information about the environment is well worth looking into. Similarly, the selection of a common plant species by two chimpanzee sub-species inhabiting two different ends of the continent does not mean that they share an ancestral artifact of plant species preference. Instead, both cases most likely represent the convergence of plant selection criteria for rough hairy surfaces as determined by the function of leaf-swallowing behavior itself.

In this light, the selection of plants used in association with bitter pith chewing may also be based on chemosensory criteria inherent in the function of the behavior itself. There may be "associative predispositions" (see Revusky, 1984) for the association of

tastes and smells that direct organisms in their search and learning processes about what makes one feel better. Bitter taste perception thresholds vary among non-human primate species, as they certainly do among human cultures, (cf. Hladik and Simmen, 1996) but bitter taste is a reliable signal of toxicity (Table 1). A number of secondary compounds ubiquitous in nature are bitter tasting (saponins, alkaloids and some sesquiterpenoids, terpenoids and steroid glycocides) and many possess important pharmacological activity (Table 1; cf. Crellin and Philpott, 1990; Githens, 1949; Shiba, 1976).

Historically, herbalists have emphasized the importance of taste and smell in the evaluation of plant medicinal properties (cf. Crellin and Philpott, 1990). In a study of the criteria of medicinal plant selection by the Tzeltal Mayans of Highland Chiapas in Mexico, Brett (1994) noted that taste and smell were consistently used to select or evaluate a plant to treat ethnomedically related illnesses. Regardless of taxonomy, bitter tasting plants were selected and predominantly used to treat gastrointestinal upsets, parasites and stomach pains (Brett, 1994). A number of bitter *Vernonia* species found across Africa and Central America, just to name a few examples, are known both for their wide ethnomedicinal use and pharmacological effectiveness against gastrointestinal related ailments, including parasitosis (e.g. Berlin and Berlin, 1996; Huffman et al., 1996a).

Individual acquisition of self medicative behaviors

Perhaps one of the most challenging questions which needs to be investigated is the way in which proposed self-medicative behaviors are individually acquired. The suggestion that self-medication is a behavioral tradition includes a range of possibilities for how the behavior started and how individuals become predisposed to ingest medicinal plants. At one extreme, animals may have an innate tendency to select appropriate plants when ill, so that the role of tradition is reduced to local enhancement (i.e., naive individuals have their attention drawn to species used by others) (Huffman and Wrang-

ham, 1994). However, in the case of leaf swallowing and bitter pith chewing it is not just what species is being ingested, but also what parts and how they are ingested that must be learned for the behavior to be effective and sometimes even for the plant to be safe to ingest. At the other extreme, chimpanzees may be averse to bitter piths and rough leaves. Given the high degree of conservatism in chimpanzee feeding habits (Nishida, 1987) random sampling of novel food items, especially when ill, does not seem likely to occur very frequently. If so, traditions must have started rarely, perhaps as a result of ill, hungry chimpanzees trying new foods during periods of extreme food scarcity, recovering their health, and associating their improved health with the new item.

Selective association between taste and gastrointestinal illness is a widely accepted principal of taste aversion learning among mammals (cf. Revusky, 1984) and the learning mechanism of food aversion in response to induced sickness has been well documented in a number of animal species (see Zahorik and Albro Houpt, 1977). While the highly adaptive significance of this reversed process, i.e., being able to associate improved health with the ingestion of novel plants having medicinal properties, seems self-evident, such learning mechanisms have received little attention (cf. Zahorik, 1977) and is an area greatly in need of further research.

Important benefits come from social learning which allows naive individuals to acquire information through the experience of others, and over time to perfect the behavior themselves (see Hikami et al., 1990; Huffman, 1996; Fragazy and Visalberghi, 1996; Galef, 1977; Nishida, 1987; Inoue-Nakamura and Matsuzawa, 1997). Once an effective self-medicative behavior is recognized, perhaps it spreads through the group, first slowly, but after a time increasingly faster as it is passed onto the youngest members of the group. At this stage, it may be just one more part of the mother's foraging and behavioral repertoire to be acquired. At Mahale, and presumably elsewhere, initial exposure to self-medicative behaviors takes place by individuals at an early age, not

when ill themselves, but by observing the behavior of those that are ill, usually their mothers (Huffman and Wrangham, 1994). Young chimpanzees have been observed on several occasions to closely watch these behaviors and immediately thereafter attempt to perform them themselves (see Huffman and Seifu, 1989; Huffman and Wrangham, 1994).

It is of considerable interest to know just to what extent primates are able to use social input to guide their appropriate choice and use of plants. For example, when ingesting the bitter pith of *V. amygdalina,* chimpanzees selectively remove the leaves and bark before ingesting the inner pith's bitter juices. In this way they avoid any significant intake of the toxic sesquiterpene lactones abundant in the leaves and bark, in favor of the more host friendly steroid glucosides. Humans have learned to use the leaves of *V. amygdalina* in moderation when mixing them with fodder for horses and other livestock as a de-wormer, or when they use the leaves themselves as medicine or in tonic foods (Huffman et al., 1996a). In striking contrast, domestic livestock do not appear to forage selectively or in moderation on *V. amygdalina* leaves, and the outcome is often lethal. Among the Temme of Sierra Leone, *V. amygdalina* is known as "a-dif-wir" which means "kill goats" (Burkill, 1985). The problem has obviously been around long enough for the plant to get this name, in spite of which goats seem not to have learned to avoid it. This may be due to the lack of an intact stable social group caused by herding practices of separating mother from young when foraging, whereby grazing aversions are not passed on from mother to infant.

A troop of Japanese macaques released into the semi-desert brushland of southern Texas learned to avoid the neurotoxic berries and leaves of *Karwinsinski humboldtiana* (Roemer & Schultes) Zucc. (Rhamnaceae) after eight individuals died and others suffered temporary paralysis from it (Fedigan, 1991). The troop was still adapting to a new environment and was feeding off many novel plant species available in the new habitat. This alone could make it quite difficult for one individual to identify the plant(s) responsible for its illness and avoid

it, let alone for other members not afflicted with paralysis to do so, too. Once preferences change, however, rapid social transmission among troop members occurs (Hikami et al., 1990).

FUTURE DIRECTIONS AND PRACTICAL APPLICATIONS
Some basic guidelines and predictions

The evidence described in this review for primates and other animal taxa suggests that a variety of behavioral adaptations exist for the control of internal and possibly external parasites. Much of the detailed evidence in support of the developing hypotheses on self-medication in the African great apes comes from their response to changing levels of parasite infection. This model should be applicable to other primate species infected with parasites exhibiting seasonal reproduction or reinfection. Other influences are likely to be operating and their possibility should not be ignored.

Systematic monitoring of individuals (not populations) throughout the year for fluctuating levels of parasite infection is an effective means of identifying the predominant parasites and their likely period of increased impact on the host (Huffman et al., 1997). Close long-term monitoring of the health of group members using detailed analysis of activity budgets (resting time, rate of locomotion, feeding time, etc.) and systematic inspection of general health signs (e.g. diarrhea, coughing, runny nose, etc.) is necessary to identify illness when it occurs and to understand the proximate effects off that illness on the individual as well as the function and effectiveness of any proposed self-medicative behavior. These procedures are straight forward and compatible with most primate field study designs.

Intestinal parasites are by no means the only influences responsible for ill health. Other sources of pathogens need to be investigated which may involve the capture and containment of animals for the collection of blood and tissue samples. The effects of intervention on observer/subject relations is a concern. It will be necessary to develop techniques to work around these difficulties.

There are limitations as to what can be done in the field and increased collaboration

between colleagues from the applied animal and plant sciences (e.g. veterinary medicine, pharmacology, natural plant product chemistry) is essential in any attempt to fully understand the implications of a proposed self-medicative behavior. The multi-disciplinary research conducted at Mahale by The C.H.I.M.P.P. Group (Chemo-ethology of Hominoid Interactions with Medicinal Plants and Parasites) is one example of how this has been effectively achieved in some areas (see Huffman, 1994; Jacobsen and Hamel, 1996).

Three of the greatest constraints on field investigations of self-medicative behavior are 1) the unpredictability of the behaviors' occurrence, 2) unreliability of being able to consistently follow and observe sick individuals over time, and 3) restraints on experimental manipulation. In order to test a number of the ideas evolving from the developing hypotheses of self-medication, these constraints must be overcome. For example, through the safe and controlled introduction of medicinal plants to captive primate social groups, it may be possible to evaluate some of the criteria of medicinal plant selection and find out how individual acquisition and group transmission occurs. Just one of the important questions begging to be answered is how do naive captive apes respond to the putative medicinal plants of their wild conspecifics? If ill and infected with nematodes, would they swallow rough hairy leaves and chew bitter pith or ignore them completely? Investigations into the potential for self-medicative behavior in captive zoo primates or other animals can be expected to greatly advance our understanding of what goes on in the wild and may provide important benefits to captive animals.

Herbal medicine and environmental enrichment in zoos

According to Jan Vermeer (Primate Keeper), since 1985 a pioneering project introducing herbal medicine into captive primate exhibits has been underway at the Apenheul Zoo in Holland (Vermeer, 1995). After determining some of the major health problems of the woolly monkey (*Lagothrix lagotricha*) population at the zoo, herb gardens were planted in plots and covered with

wire mesh. The mesh is set high enough above the ground to prevent primates from completely destroying the plants, but low enough to allow access to the distal branches of herbs as forage. Among the plants reported to be used are several common European herb species noted for their activity against stress (Wild Chamomile (*Matricaria chamonilla* (Linn.) (Compositae); Catnip *Nepeta cataria* (Linn.) (Labiatae); Lavender *Lavendula augustifolia* (Labiatae)), hypertension (Garlic *Allium sativum* (Linn.) (Liliaceae); Hawthorn *Crataegus oxyacantha* (Linn.) (Roseaceae)) and bladder infection (Common Berberry *Berberis vulgaris* (Linn.) (Berberidaceae); Fennel *Foeniculum vulgari* (Gaert.) (Umbelliferae)). The actual effects of these plants on the health of the woolly monkeys have not yet been clinically evaluated.

A similar project was begun at the Denver Zoo in Colorado in 1996 under the direction of Merle Moore (Program Administrator, Horticulture and Landscape Maintenance). Wire mesh gardens similar to those used at Apenheul have been placed in the gorilla and orangutan outdoor exhibits at the zoo's new Primate Panorama exhibit. Beyond the potential for providing health promoting herbs and educational awareness about the use of medicinal plants by primates in the wild, these two programs exemplify new and innovative ways of maintaining a self-sustaining source of environmental- and diet-enrichment in zoo exhibits (Vermeer, 1995). Further studies are encouraged to evaluate locally available plants for use also in the zoos of developing countries around the world.

Sustainable resources of medicine for livestock in developing countries

One future direction in sight for the field of self-medication is the application of knowledge gained about medicinal plants and their uses to the human and veterinary medical sciences. *Oesophagostomum* spp. infections are common in non-human primates, pigs, sheep, cattle and occasionally humans, and are considered significant pathogens (cf. Anderson, 1992; Brack, 1997; Polderman et al., 1991). While a number of broad spectrum anthelmintics are currently

available for the treatment of livestock, growing chemoresistance to these anthelmintics and the prohibitive costs of such drugs to rural livestock owners and zoological parks in developing African nations make their use impractical if not at times impossible (Jackson, 1993; Mathias et al., 1996; Roepstorff et al., 1987).

Recently, great interest has been taken in looking for new ways of treatment using natural plant products derived from ethnomedicine (cf. Kasonia and Ansay, 1994; McCorkle et al., 1996; Bøgh et al., 1996). The study of self-medication in great apes too can be expected to provide equally viable sources of natural products for the effective treatment of parasitosis in humans, domestic and captive animals (Berry et al., 1995). Based on the results of work at Mahale, a joint effort between the Danish Centre for Experimental Parasitology (The Royal Veterinary and Agricultural University, Copenhagen), the Sokoine University of Agriculture (Morogoro, Tanzania), The University of Dar es Salaam (Dar es Salaam, Tanzania) and the author is being made to determine the in vitro efficacy of these plants against *Oesophagostomum* infections in swine under controlled laboratory conditions. This will allow for the controlled testing of the bitter pith chewing and leaf swallowing nematode control hypotheses in apes and to access the potential of these endemic, readily available and sustainable plants as sources of antiparasitics in Africa.

Expectations for the future

Further field and laboratory research into self-medicative behavior in other primate species is strongly encouraged. As this review has shown, answers to a few questions invariably lead to more questions. As more researchers in the field begin to look for similar types of behavior, they will be found and more answers will be provided. Because of the obvious adaptive significance of self-medication, its existence is predicted to be wide-spread. Other types of self-medicative behavior are predicted to occur in the great apes as well as in monkeys and prosimians. The challenge is in finding what the immediate threats to health and survival are in a population and by what means they are dealt with by that particular species.

The use of dietary clay by humans to detoxify food plants high in secondary compound content is considered to have expanded the availability of food to modern humans beyond that which was available to our prehominid ancestors (Johns, 1990). From golden bamboo lemurs to apes, the frequent ingestion of clay soils among primates may also play an important role in allowing primates to widen their dietary repretoir, especially at certain critical times of the year. The strong similarities in plant selection criteria among the African great apes and the common use of some plants by chimpanzees and humans for similar illnesses is tantalizing evidence for the evolution of self-medication. In this light, our hominid ancestors can be predicted to have exhibited some similarities in plant selection criteria with both extant apes and modern humans. The fossil record provides no direct evidence for the finer subtleties of feeding behavior and diet, but it seems reasonable to hypothesize that early hominids would have displayed at least the range of extant ape self-medicative behaviors.

Whether it be chimpanzees selectively ingesting plants in ways that lead to the seasonal expulsion of certain parasites or the influence of phenology and diet on the onset of mating in female vervet monkeys, the complexity of primate, parasite, and plant interactions cannot be denied. Study of these interactions in the framework of self-medication provide a new and entirely novel level of complexity to our understanding of primate behavioral ecology.

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