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Plantago spp. AND *Bidens* spp.: A CASE STUDY OF CHANGE IN HAWAIIAN HERBAL MEDICINE

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ABSTRACT.—The substitution of alien species for native plants in Hawaiian traditional medicine is discussed. Substitutions examined are the switch from various native *Bidens* spp. to the more ubiquitous *Bidens pilosa* L. and the switch from the native plantains, *Plantago pachyphylla* A. Gray, *Plantago hawaiensis* A. Gray, and *Plantago princeps* Cham. and Schlechtend, to *Plantago major* L. Historical, cultural, and scientific data are synthesized to examine these changes in the traditional Hawaiian pharmacopoeia. Major elements that affect the inclusion of new plants in the Hawaiian pharmacopoeia are availability and biological activity. This process of inclusion also provides insight into how indigenous scientists adapt pharmacological traditions to the changing biological and cultural environment.

Key words: Hawaii, *la'au lapa'au*, ethnomedicine, *Bidens*, *Plantago*.

RESUMO.—A substituição de espécies introduzidas pelas plantas nativas na medicina tradicional do Havaí é debatida. As substituições examinadas são das espécies de *Bidens* nativas para *Bidens pilosa* e a substituição das *Plantago* spp. nativas, inclusive *Plantago pachyphylla*, *P. hawaiensis* e *P. princeps*, para *Plantago major*. Os aspectos históricos, culturais e científicos são sintetizados para examinar estas mudanças na farmacopéia tradicional do Havaí. Os dois elementos mais importantes na inclusão de novas plantas na etnofarmacopéia do Havaí são a facilidade de acesso das plantas e atividade biológico. Este processo ensina como cientistas indígenas adaptam tradições farmacológicos às mudanças nos meios biológico e cultural.

RÉSUMÉ.—Cette étude rend compte de l'utilisation d'espèces introduites aux dépens des plantes indigènes dans la médecine traditionnelle hawaiienne. La plante ubiquiste, *Bidens pilosa* L., ainsi que le *Plantago major* L., ont remplacé respectivement plusieurs *Bidens* spp. indigènes et les *Plantago pachyphylla* A. Gray, *P. hawaiensis* A. Gray et *P. princeps* Cham. et Schlecht. Afin de comprendre ces changements dans la pharmacopée traditionnelle hawaiienne, une synthèse des données historiques, culturelles, et scientifiques a été faite. Les principaux facteurs déterminant l'inclusion de nouvelles plantes dans la pharmacopée hawaiienne résident dans leur disponibilité et leur activité biologique. Également, ce processus d'inclusion permet de mieux saisir comment les «scientifiques autochtones» ont adapté leurs traditions pharmacologiques selon les changements survenus dans leurs environnements biologique et culturel.

INTRODUCTION

The purpose of this paper is to synthesize disparate cultural, historical and biological information to examine the factors that influence the adoption of *Bidens*

pilosa and *Plantago major* into the traditional Hawaiian pharmacopoeia. Previous botanical, ethnobotanical, demographic, historical, and cultural research provides background on the plants, as well as their ethnobotanical history in Hawaii. Personal interviews let Hawaiians speak for themselves about the plants and the processes of adoption and substitution. A literature search of pharmacological tests as well as antibacterial screening offers insight into the comparative biological activity of the native and introduced species, an important factor in the introduction and use of a new plant species. Substitutions appear to be a result of a variety of cultural factors including empirical testing and observation to determine biological activity, spiritual inspiration, and other ecological considerations such as availability of plant material.

The Hawaiian Islands provides an excellent place for a study of the evolution of a pharmacopoeia because both its flora and traditional herbal medicine have been well studied. It is also significant that, even after the introduction of the western medical system in Hawaii, the traditional healing system has continued to be practiced and even expanded in recent years due to a Hawaiian cultural renaissance. Over the years, the traditional herbal medicine system (*la'au lapa'au*) has adapted to the changing biological and cultural environment. The substitution of *Bidens pilosa* L. and *Plantago major* L. for native species exemplifies this process.

A growing body of ethnobotanical research has begun to examine the origin and evolution of traditional medicine. For example, some recent research suggests that indigenous groups in pre-European contact America had much different pharmacopoeias than they do now, and the introduction of new diseases prompted the discovery of new plant medicines in the relatively short amount of time after the Europeans' arrival in the New World (Davis 1995). The simultaneous introduction of new diseases and new plants seems to potentially result in the expansion of medicinal plant use through scientific experimentation. Bennet and Prance (2000) found 216 post-European introduced plants that are a part of the indigenous pharmacopoeias of northern South America.

Other recent ethnobotanical studies illustrate how indigenous people experiment with plants. For example, around 40% of the plants in the local pharmacopoeia in 1995 were unknown to the sixteenth-century Portuguese settlers when they arrived in the Madeiras; they were either introduced from Africa or the Americas or were native to the islands (Rivera and Obon 1995). Similarly, Paul (2002) found that 40% of Haitian medicinal plants belong to genera that have similar medical uses in West Africa. This illustrates the tendency to adopt new species of the same genus when confronted with changed ecological conditions brought about by migration.

Some ethnobotanists focus on indigenous adaptations to these changed environmental circumstances. They theorize about the origins of a pharmacopoeia and the experimental processes by which new medicinal plants are selected. Moerman (1998) hypothesizes that plants used for medicine in traditional society will be those that are available, perennial, and widespread geographically, as well as easily noticed, large and distinctive. Perennials, especially larger tree species, live longer and thus generally have more secondary chemicals, making them more useful as medicinal plants. The other characteristics all have to do with the ease of finding and recognizing medicinal plants. Johns (1990) discusses the selection

of new medicinal plants focusing on the methods by which biological activity of plants is discovered—including taste, odor, empirical testing, and the observation of animals.

Cox (1995) explains how Kuhn's (1965) work on scientific paradigms provides a method of understanding indigenous scientific processes. Indigenous healers operate in paradigms that differ from those of western science and these paradigms, in turn, direct the hypotheses and methodologies of indigenous experimentation (Cox 1995). Indigenous healers do, however, follow the scientific method, making observations, developing theories, and then using this knowledge and experience to predict future outcomes.

Origins and Evolution of the Hawaiian Pharmacopoeia.—In Polynesia, there is some debate about the origin of its herbal medicine tradition. Whistler (1992) has argued that Polynesians had a limited herbal medicine tradition, especially in relation to medicines taken internally. He shows that prior to European arrival, Polynesians had few infectious diseases, and as a result, the medical system was focused around external ailments such as wounds, sprains, rashes, and infections. More complex diseases were treated with spiritual healing, and the plants used in this process were "fetid herbal preparations applied externally or taken internally that were believed to have the power to repulse malicious spirits and to thereby heal" (Whistler 1992:37–38). Consequently, the complex Hawaiian medical system described by early native historians developed in the mid-nineteenth century in response to the introduced epidemic diseases and contact with medicine from European and other more developed herbal medical traditions, and "the widespread use of medicines for internal ailments that is so prevalent in Polynesia medicine today appears to have developed after, and as a result of, contact with the western world" (Whistler 1992:38).

Cox (1991), however, suggests that herbal medicine in Polynesia is a conservative tradition, in that most knowledge is gained from a mentor and not through experimentation (although he recognizes that new plant remedies are sometimes acquired in dreams). Cox extends these arguments to explain how Polynesian herbal medicine developed before western contact. He discounts early missionary histories relied on by Whistler and then supports this claim by noting the similarity between different medical traditions within Polynesia, the variation among different family traditions (a European introduced system would look more locally homogenous), Polynesian belief in the endemic nature of their healing traditions, and the fact that a majority of plants used medicinally in Polynesia are not used in other parts of the world.

Abbott and Shimazu (1985:220) comment that Hawaiians "have a tendency to stick to tried and true remedies," which mainly consist of plants the Polynesians carried with them throughout the Pacific. They note however, that many endemic plants are used, although less frequently, and that some plants introduced after European contact have also been added. This supports Cox's notion of the endemic origin of Polynesian herbal medicine based on similarities between different Polynesian pharmacopoeias.

Many of the processes observed in the evolution of traditional pharmacopoeias in other parts of the world apply to Hawaii. The introduction of infectious

diseases and new plants, the migration of other ethnic groups to Hawaii, and the decreasing availability of native plant species all had an effect on the pharmacopoeia. The Hawaiian pharmacopoeia, like many others, has had rapid development and change in the number and species of plants used in the relatively short period since European contact. While this study does not directly address the origin of the Hawaiian pharmacopoeia nor the importance of Polynesian introduced plants to it, it does reveal some of the processes behind the introduction of new plants to Hawaiian herbal medicine, presenting a dynamic view of the evolution of the Hawaiian ethnomedical tradition.

Two methods for the discovery of new medicinal plants are evident in Hawaii: empirical practice and spiritual guidance. Handy describes the origins of medicinal plant usage in Hawaii,

> It will be plain to anyone that makes even a superficial study of Hawaiian medicine that the system has arisen mainly through empirical practice. . . . Many Hawaiians will tell you that the system has been established through a trial and error method, but that the original knowledge of the healing qualities of various elements used has always been, and is still, revealed by the ancestral *aumakua* [spirits] in dreams. Handy (1934:16)

Empirical practice is a research method based on experimentation and observation, much like the scientific method. According to Larsen (1946:19), ancient Hawaiians were "developing a system of medicine that was built upon observation, deduction, experimentation, and clinical trial," but that "this system was lost as their whole culture succumbed to the pompous tide of European conquest" (Larsen 1946:19). From the observations made in this paper it is clear that the experimentation, observation, and deduction in Hawaiian traditional medicine continued long after European conquest.

While this study focuses on the empirical processes behind the discovery of new medicinal plants, the spiritual roots of Hawaiian healing cannot be ignored: in Hawaiian healing traditions, spiritual guidance is an essential element in the discovery of new plant material. In the ethnoscientific paradigm of *la'au lapa'au*, dreams, visions, and inspired thoughts provide *la'au* practitioners with hypotheses from which they can begin the empirical testing process for new remedies (Cox 1995).

REVIEW OF THE ETHNOBOTANICAL AND BOTANICAL LITERATURE

Bidens spp.—The nineteen endemic *Bidens* species in Hawaii evolved through adaptive radiation from a single primal ancestor (Ganders 2000; Wagner et al. 1999). All the species are interfertile, but most do not occur sympatrically (Ganders and Nagata 1984). In modern times four species have been introduced: *Bidens pilosa* L., *B. cynapiifolia* Kunth, *B. alba* (L.) D.C., and *B. gardneri* Baker. *Bidens pilosa*, which first arrived sometime before 1845, is native to the tropical Americas (Wagner et al. 1999). *Bidens cynapiifolia* was first collected in 1929, almost seventy years later (Degener 3781 BISH), *B. alba* in 1958 (Pearsall s.n., BISH), and lastly *B. gardneri* in 1983 (Hobdy 1883 BISH). *Bidens alba* and *B. pilosa* are both widespread in

low lying disturbed areas with *B. alba* becoming increasingly more abundant on Oahu (Wagner et al. 1999).

Generally, a distinction is made between native species of *Bidens*, called *ko'oko'olau* or *ko'olau*, and the non-native *B. pilosa*, which is called *kinehi*. However, there is still some ambiguity and *ko'oko'olau* can be used to refer to any species of *Bidens*. For example, Kaiahua identifies *ko'oko'olau* as *B. pilosa*. He also mentions that there are two kinds of *ko'oko'olau*, indicating that the term *ko'oko'olau* can be used to refer to more than one species (Kaiahua 1997). Comparing the use of native and introduced *Bidens* species is thus complicated because most texts make no attempt to distinguish among them. A source ascribed to Kupunihana, written around 1922, mentions three types of *ko'oko'olau* used as medicine for stomach ailments and numerous other ailments, indicating that many of the species within the genus were recognized and used medicinally (Chun 1998). None of the early texts, even into the early twentieth century, use the term *kinehi* (Chun 1994a, 1994b, 1998; Handy et al. 1934; Kaiakamanu and Akina 1922; Kamakau 1964).

Nineteenth-century sources on Hawaiian herbal medicine mention that *ko'oko'olau* is useful for asthma, throat and stomach troubles, stimulating the appetite, general debility of the body, childhood ailments, as a purgative (with other plants), and as a tonic (Chun 1994a; Kaaiakamanu and Akina 1922). All of the treatments that were common in precontact times are for ailments that are easily recognizeable (sore throat, general debility, stomach troubles). Thus, following Whistler's logic, they are more likely to have been treated with an herbal remedy during precontact times.

The earliest mention on *ko'oko'olau* in the literature is in 1866 in Kamakau (1964) and the 'Ahahui report in 1867 (Chun 1994a). After this, *ko'oko'olau* is mentioned in a number of other studies on Hawaiian herbal medicines (Chun 1994a, 1994b, 1998; Handy et al. 1934; Judd 1997; Kaiakamanu and Akina 1922; Kamakau 1964; McBride 1979), whereas *kinehi* is only mentioned in one published sources (Kaiahua 1997). This suggests the native species were more widely used until recently. *Ko'oko'olau* was also used to treat a wide variety of endemic health conditions, suggesting that the native plant has been used since before European contact. It would appear from the widespread use of *B. pilosa*, its early introduction, as well as the variety of *Bidens* species that are used, that *B. pilosa* has been in the pharmacopoeia for some time, even if the name *kinehi* appears only recently in the ethnobotanical literature.

Plantago spp.—The genus *Plantago* is a similar example of substitution. Multiple native and introduced species have been reported to have medicinal use. The taxonomy of endemic plantains, however, is much simpler. There are three endemic species: *Plantago hawaiiensis* A. Gray, *P. pachyphylla* A. Gray, and *P. princeps* Cham. and Schlechtend. *P. pachyphylla* and *P. hawaiiensis* appear to be more closely related to each other than to *P. princeps* (Wagner et al. 1999). There are five introduced species, including *Plantago major* and *P. lanceolata*. *P. major* is widespread throughout the Hawaiian Islands and was first collected in 1864–1865 (Mann and Brigham 423, BISH). *P. lanceolata* was first collected on Kauai in 1895 (Heller 2457, BISH). The other alien species are more recently introduced and less widely distributed (Wagner et al. 1999).

The Hawaiian generic name for *Plantago* is *laukahi*. The native species are referred to as *laukahi kuahiwi*, indicating that they are found in the mountains. The native species also have other names that differentiate between them, *manene* for *P. pachyphylla*, and *ale* for *P. princeps* (Wagner et al. 1999).

Laukahi is used as a purge for mother and babies, to draw the pus out of sores and boils, and to cure the diseases of *pa'ao'ao* and *'ea* (Chun 1994b, 1998) Other authors mention that *laukahi* is used as a tonic, a laxative, a poultice for boils and sores, and as a tea for diabetes, urinary tract infections, kidney problems, pulmonary disease, and high blood pressure (Gross 1998; Handy et al. 1934; Kaiahua 1997; Krauss 1979; Nagata 1970; Whistler 1992). Interestingly *laukahi* is used to treat ancient Hawaiian disease categories (*pa'ao'ao*) as well as more modern ailments (diabetes, high blood pressure) and external, internal, and 'spiritual' disease categories, suggesting that new plants are not just adopted to treat new diseases.

There is some disagreement on whether or not the native *Plantago* species were used in precontact Hawaiian herbal remedies. Krauss (1979, 1993, 2001) and Gross (1998) suggest that the introduced *P. major* replaced the native *Plantago* species while Whistler concludes that

> Several authors have reported that these native plantains were the original medicinal species and that the introduced weed *Plantago major* has replaced it, presumably because the latter is so common and easy to obtain. It is more likely, however, that *Plantago major* was the first and perhaps the only species commonly used in Hawaiian medicine. (Whistler 1992: 188)

Given the widespread medicinal use of *Plantago* throughout the world, this is plausible (Basaran 1996; Bayon 2000; Henderson 1994; Johnson 1999; Ramos 1996). A children's book on Hawaiian herbal medicine mentions that the Japanese, who migrated to Hawaii in large numbers, also use *Plantago major* in a similar manner to the Hawaiians (Corum 1985). Most of the immigrants who came to Hawaii arrived well before 1922 (Juvik and Juvik 1998), the date of the first study that specifically mentions and describes the medicinal use of *laukahi lauli'i* (clearly identifying *P. major*) (Kaaiakamanu and Akina 1922). This allows time for significant interaction between Hawaiians and new immigrants, supporting Whistler's (1992) claim.

However, in support of the use of native *Plantago* spp., the earliest reference to *laukahi* is found in Kamakau's writing about the people of old Hawaii. This work was published in a Hawaiian language newspaper series from 1866–1871, around the time the Chinese first immigrated but before they had moved throughout the Islands. Another early reference is found in a group of interviews conducted with a variety of healers in 1867 as part of the establishment of a native Hawaiian healers' organization (Chun 1994a). Five different healers all used *laukahi* in many different ways. One healer, Pupuka, even specifically mentions the use of *laukahi kuahiwi*, referring to one of the native species. These sources seem to confirm the early widespread use of *Plantago*, definitely including the native species and possibly *P. major*. The number of different people using *Plantago* spp.

and the early date of use all seem to indicate a switch from the use native *Plantago* spp. to the introduced *Plantago major.*

After this 1867 mention of *laukahi kuahiwi* there is no specific mention of the use of the native *Plantago* species besides Krauss (1979, 1993, 2001) and Gross (1998) (who mention it being replaced with *P. major,* not its contemporary use. Whenever *laukahi* is subsequently mentioned in research on Hawaiian herbal medicine it is always identified as *P. major* (Gross 1998; Handy et al. 1934; Kaiahua 1997; Kaiakamanu and Akina 1922; Krauss 1979; Nagata 1970; McBride 1979; Whistler 1992). Bushnell et al. (1950) suggest that *P. lanceolata* is also used as medicine, however, the source material he cites—Kaaiakamanu and Akina (1922)—does not support this assertion. This information, plus the conspicuous absence of current references to all other *Plantago* spp., strongly suggests that *P. major* is currently the only member of genus used in the Hawaiian pharmacopoeia and it probably replaced the use of the native species.

Antibacterial Assays for Bidens *spp. and* Plantago *spp.*—The widespread use of both *Bidens* spp. and *Plantago* spp. in traditional medicine has stimulated a significant amount of research on their biological activity (Table 1). These studies suggest a broad range of healing affects from both *Bidens* and *Plantago* species. *Bidens* has been screened for antibacterial activity, a treatment for liver diseases, and an anti-ulcer treatment; *Plantago* spp. has been tested for anti-inflammatory and wound-healing properties. Thus, the biological activity of both *Bidens* spp. and *Plantago* spp. is consistent with their uses in the Hawaiian pharmacopoeia, suggesting that Hawaiian healers possessed a sophisticated knowledge of biological activity.

The biological activity of *Bidens* is due to large classes of compounds: polyacetylenes and flavonoids.[1] Marchant et al. (1984) researched polyacetylene content in Hawaiian *Bidens* species and found a surprising array of different molecules in different species. While all contained polyacetylenes in their roots, thirteen species did not contain any polyacetylenes in their leaves, suggesting highly variable antibacterial activity within the native *Bidens* species. The native species *Bidens macrocarpa* (A. Gray) Sherff, *Bidens populifolia* Sherff, and *Bidens campylotheca* Schultz-Bip. all contained some level of polyacetylenes in their leaves, which indicates that the leaves have antimicrobial properties (Marchant et al. 1984).

METHODOLOGY

Interviews.—Semi-structured interviews were conducted with both specialists and nonspecialists.[2] The purpose of the research was explained and verbal consent granted. The participants were questioned about their knowledge of both introduced and native species of *Bidens* and *Plantago* and their uses and relative effectiveness, as well as possible reasons for the preference of one species over another. When possible, the plants were examined in the field or shown to the participants. In other cases, the plants were described with salient features to distinguish between species. All the species in question had some visible, easily distinguishable features (e.g., yellow versus white flowers, narrow versus rounded leaves).

Antibacterial Assays.—The selection the plants species for the antibacterial assays was dependent on locally available species. The introduced *B. pilosa, P. major,* and

TABLE 1.—A summary of some of the pharmacological studies done on biological activity of *Bidens* spp. and *Plantago* spp.

Plant	Study	Results
B. pilosa	Bushnell et al. 1950	Antibacterial—moderately effective; anti-enteric pathogens—moderately effective
	Wat et al. 1979	Polyacetelynes are phototoxic to bacteria and fungi
	N'Dounga et al. 1983	Antibacterial activity
	Machado et al. 1988	Antiparasitic activity
	Geissberger et al. 1991	Antihypertensive
	Sarg et al. 1991	Anti-ulcer activity
	Chih et al. 1995	Anti-inflammatory
	Gupta et al. 1996	Tumor inhibition; cytotoxicity; DNA intercalation; brine shrimp toxicity
	Jager et al. 1996	Prostaglandin-synthesis inhibition
	Chih et al. 1996	Protect liver injuries from various hepatotoxins and have antihepatic agents
	Alvarez et al. 1996	Antimicrobial; cytotoxic; insecticidal
	Rabe and Van Staden 1997	Antibacterial activity
	Brandao et al. 1997	Antimalarial
	Pereira et al. 1999	Immunosuppressant activity
	Dimo et al. 1999	Antimicrobial activity
	Alvarez et al. 1999	Antimicrobial; not antidiabetic
	Tan et al. 2000	Possible anti-ulcer effects
	Ubillas et al. 2000	Antihyperglycemic
	Dimo et al. 2001	Hypotensive effect
	Khan et al. 2001	Antimicrobial
	Chang et al. 2001	Possible treatment for leukemia
B. campylotheca	Redl et al. 1994	Anti-inflammatory active polyacetylenes
B. subalternans	Ortega et al. 1998	Anti-inflammatory
B. aurea	La Case et al. 1995	Anti-ulcer agent
	Martin et al. 1996	Anti-ulcer agent
B. alba	Lopez et al. 2001	Does not modify insulin or glucose levels

TABLE 1—(continued)

Plant	Study	Results
P. major	Bushnell et al. 1950	Antibacterial—moderately effective; anti-enteric pathogens—slightly effective
	Ravn and Brimer 1988	Anti-inflammatory and analgesic activity
	Dat et al. 1992	No diuretic activity
	Guillen et al. 1997	Component plantanajoside has possible antibacterial effects
	Ringborn et al. 1998	Anti-inflammatory; anti-ulcer by inhibition of COX-2 enzyme
	Michaelson et al. 2000	Possible wound healing effects
	Hetland et al. 2000	Polysaccharide fraction PMI protects against pneumococcal infection
	Ikawati et al. 2001	Inhibited IgE-dependent histamine; possible asthma or allergenic disease uses
P. lanceolata	Marchesan et al. 1998	Anti-inflammatory
	Deliorman et al. 1999	Hepatoprotective effects
	Schmidgall et al. 2000	Moderate activity on treatment of irritated buccal membranes.
P. asiatica	Tezuka et al. 2001	Anti-inflammatory

P. lanceolata were readily obtained from the lawns on the Brigham Young University-Hawaii campus while *P. pachyphylla* required long hike to the summit of the Ko'olaus. Similarly, many of the native *Bidens* species are rare and occur in small, localized populations (Wagner et al. 1999) although they are generally more common than the *Plantago* species. Voucher specimens were collected.[3]

For *Plantago* spp. the antibacterial screening portion of this study includes only one native species, *P. pachyphylla* (I was unable to collect *Plantago hawaiensis* and *P. princeps* because they are endangered species and have very limited distributions), and the introduced species of *P. major* and *P. lanceolata* (Wagner et al. 1999). For *Bidens* spp., the three native species endemic to the northeastern section of the Ko'olau Mountains—*Bidens populifolia, B. macrocarpa,* and *B. campylopthecа*—were screened along with the two most common introduced species—*B. pilosa* and *B. alba.*

An agar diffusion method (Ingraham and Ingraham 2000) was used to analyze the antibacterial properties of native *Bidens* in comparison with the introduced species, and the native *Plantago pachyphylla* in comparison with the introduced *P. major* and *Plantago lanceolata.*

All eight plants were tested against *Staphylococcus aureus* and *Escherichia coli* bacteria. These microorganisms were used because they are common skin and digestive tract microorganisms and correspond with Hawaiian uses of *Bidens* and *Plantago* spp. They also offer examples of Gram-negative and Gram-positive bacteria and are common test organisms, allowing for comparison with other antibacterial studies. (Bushnell et al. 1950; Locher et al. 1995).

Fresh plant material including leaves and stems was blended and squeezed with a garlic press to obtain the plant extract. One or more plants were used depending on the amount of liquid extracted per plant. However, all plants of a given species used for antibacterial assays as well as separate voucher specimen were collected from the same site. No solvent was added. Plant extract (0.75 ml) was applied to a 3-mm diameter paper disk. The paper disk was placed in a petri dish of Mueller-Hinton agar inoculated with either the *Escherichia coli* (Migula 1895) Castellani and Chalmers 1919 or *Staphylococcus aureus* Rosenbach 1884. Each dish contained both positive and negative controls—a commercially prepared antibiotic disk (Erythromycin) and a blank paper disk. Five plates were prepared for each plant to be tested. The petri dishes were incubated for 24 hours at 37.5°C. The zone of inhibition was then measured in millimeters.

It is important to note that an agar diffusion method does not offer a complete picture of the multiplicity of possible medicinal effects of the plants such as the potential interactions of plant compound in a living system or in conjunction with other plant mixtures. It does, however, offer some insight into the comparative biological activity against certain bacteria.

RESULTS AND DISCUSSION

Interviews.—Personal interviews, including those with both healers and nonhealers, provided the most important source of information regarding the introduction of new plants into the Hawaiian pharmacopoeia. Today, *kinehi* (*B. pilosa*) and *ko'oko'olau* (native *Bidens*) are used topically to cleanse wounds, heal sunburns and

insect bites, and to strengthen the body (often in conjunction with more powerful traditional medicine). While the names for the various species of *Bidens* are sometimes used interchangeably, all of the people interviewed, healer and nonhealers, knew about the use of *Bidens* and recognized the difference between the native and introduced species, even if they had never used the native species.

Students of the late Papa Auwae, a well-known *la'au lapa'au* practitioner, described how he taught that *kinehi* is more potent than the native *ko'oko'olau* and is useful in treating a wider variety of illnesses. The *ko'oko'olau* is used as a general tonic, whereas *kinehi* is used to treat all manner of internal ailments. He also taught that the potency of the different *Bidens* populations is also dependent on the location from which the plant was gathered, possibly indicating a much more sophisticated knowledge of bioactivity of *Bidens*.[4] Another interview suggests that the plants were mixed to achieve various effects and possibly to control the potency. Some people prefer *kinehi* or *ko'oko'olau* because of taste and custom. Taste, however, may also be an indicator of biological activity (Johns 1990). This suggests that people recognize the differences in biological activity among different species, which is an important factor in favoring the use of one species over another and the adoption of new plants into the pharmacopoeia.

Authors on contemporary *la'au lapa'au* practices most often cite availability as the reason for the introduction of new plants into the herbal medicine tradition (Judd 1997; Krauss 1979). Krauss (1979) specifically mentions that *kinehi* is used in place of the native *ko'oko'olau* because of its availability. People interviewed also indicated that availability was an important factor in the decision to use the introduced plants. Many people using traditional medicine are aged and are unwilling to hike into the mountains to find the native *Bidens* and *Plantago* species, especially when a similar plant is growing in their front yard. Plants, especially those with healing properties, are seen as gifts from God, and it makes sense that God would make a useful plant readily available. Personal experience while gathering plants on Oahu for this project also supports the idea that the introduced plants are much more readily available. This is due, in part, to the degradation of native ecosystems. Native plants are limited to small areas higher up in the mountains (Juvik and Juvik 1998).

In sum, in the case of *Bidens*, there is no simple substitution. The reality is much more complex. Both native and introduced species are still used, sometimes together, and the decision to use one or the other is based on the availability, biological activity, disease to be treated, personal preference (taste), and familiarity with the plant.

Although the use of *P. major* is widespread, there is no use and little knowledge of any of the native *Plantago* species. The literature about contemporary *la'au lapa'au* practitioners does not mention the native species (Judd 1997; Kaiahua 1997; McBride 1979). While Krauss and Whistler comment on the switch from the native to the introduced *Plantago* (Krauss 1979, 1993; Whistler 1990), people interviewed for this study did not recognize the medicinal uses of the native *Plantago* species. The rarity of the native species compared to the ready availability of *P. major* seems to account for the complete substitution of the native *Plantago* species with *P. major*.

Another important lesson learned from Hawaiian *la'au* practitioners is that

the spiritual component of healing is absolutely essential. Four people mentioned that 80% of healing is "spiritual" while only 20% comes from the biological activity of the plants. In addition, plants are seen as gifts from God to aid in the healing process, so it could be said that all healing comes from God. Furthermore, divine inspiration is an essential source of knowledge about new medicinal plants. There are stories of people being inspired to use a new plant that they had never used medicinally before. This seems to be a common local explanation for the addition of new plants into the pharmacopoeia.

Antibacterial Assays.—In the case of *Bidens*, both native and introduced species have antibacterial activities. The most activity was found in *B. macrocarpa* and *B. pilosa*. While the native species all exhibit some antibacterial activity, there is quite a bit of variability between the different species (Table 2). A study comparing *B. campylotheca* to *B. pilosa* for antimalarial activity found both to have antimalarial activity with *B. pilosa* being more effective (Brandao et al. 1997). This correlates with native Hawaiian perceptions of comparative biological activity of the native *Bidens* spp. and *B. pilosa*. The decline in use of the native species may be a function of the variable antibacterial activity (depending on the species) as well as decreasing availability. *Bidens alba*, although readily available on Oahu (more so than any other *Bidens* species), is rarely used medicinally. Its moderate antibacterial activity suggests that this maybe a function not only of its recent introduction to Hawaii but also its moderate biological activity. Although this study did not include alternative *Bidens* extracts (e.g., methanol, ethanol, EtOAc, petrol, CH_2Cl), it is important to note that other tests that have included them have shown significantly greater antibacterial activity (Jager et al. 1996; Khan et al. 2001; Rabe and van Staden 1997).

Initially, it was not possible to detect variable antibacterial activity among the native and introduced *Plantago* spp. Given that native preparations of *Plantago major* usually include rock salt and that pharmacological studies of *Plantago* spp. found significantly more activity with methanol extracts (Guillen et al. 1997; Tezuka et al. 2001), salt and methanol extracts of *P. major* were made and tested. However, still no antibacterial activity was found (Table 3). It is possible that the strains of bacteria have developed some kind of resistance to certain antibacterials or that the chemical constituents of *P. major* vary between different populations depending on environmental and/or genetic conditions. Other kinds of biological activity besides antibacterial (anti-inflammatory, wound healing effects, etc.) could also explain the use of *Plantago* spp. in the Hawaiian pharmacopoeia. The widespread use of a variety of *Plantago* species in ethnomedical traditions throughout the world (Bayon 2000) and previous pharmacological studies suggest that *P. major* and the *Plantago* genus (possibly including the endemic Hawaiian species) are biologically active.

CONCLUSION

Substitutions and additions of *Plantago* and *Bidens* species to the Hawaiian pharmacopoeia appear to be the result of myriad intermingled biological and cultural factors. This study indicates that some of these elements could include:

TABLE 2.—Comparative antibacterial activity of native and introduced *Bidens* species.

	Native		Introduced		
	B. macrocarpa	*B. campylotheca*	*B. populifolia*	*B. alba*	*B. pilosa*
E. coli					
Plant	9.8 ± 0.2 (n = 5)	8.0 ± 0.8 (n = 4)	— (n = 5)	16.3 ± 9.4 (n = 3)	8.0 ± 1.1 (n = 5)
Erythromycin	17.4 ± 0.4 (n = 5)	17.8 ± 1.0 (n = 5)	16.8 ± 0.7 (n = 5)	14.0 ± 1.0 (n = 5)	16.2 ± 1.1 (n = 5)
S. aureus					
Plant	7.0 ± 0.4 (n = 5)	3.2 ± 0.2 (n = 4)	4.5 ± 1.5 (n = 2)	3 (n = 1)	8.8 ± 0.4 (n = 5)
Erythromycin	14.0 ± 0.3 (n = 5)	11.6 ± 1.1 (n = 5)	10.4 ± 1.7 (n = 5)	12.2 ± 0.7 (n = 5)	11.0 ± 0.3 (n = 5)

Antibacterial activity indicated by radii of the rings of inhibition measured in millimeters; not detected (—): for all five runs rings of inhibition measured <0.5 mm.

Five trials were undertaken for each plant. Whenever one or more trial was unsuccessful (ring of inhibition <0.5 mm), that trial was not included in the statistical assessment; rejected data of this kind are indicated by the n value.

TABLE 3.—Comparative antibacterial activity of native and introduced *Plantago* species.

	Native	Introduced	
	P. pachyphylla	*P. major*	*P. lanceolata*
E. coli			
Plant	—	—	—
	(n = 5)	(n = 5)	(n = 5)
Erythromycin	16.0 ± 0.5	16.0 ± 1.5	17.2 ± 0.4
	(n = 5)	(n = 5)	(n = 5)
S. aureus			
Plant	—	—	—
	(n = 5)	(n = 5)	(n = 5)
Erythromycin	10.2 ± 0.4	10.5 ± 1.4	10.8 ± 0.9
	(n = 5)	(n = 4)	(n = 5)

Antibacterial activity indicated by radii of the rings of inhibition measured in millimeters; not detected (—): all five runs rings of inhibition measured <0.5 mm.
Five trials were undertaken for each plant. Whenever one or more trial was unsuccessful (ring of inhibition <0.5 mm), that trial was not included in the statistical assessment; rejected data of this kind are indicated by the n value.

availability of the introduced and native plants, often as a result of environmental degradation; biological activity of the plant; and a variety of cultural factors, including the spiritual component of traditional Hawaiian healing, interaction with different immigrant groups, time of introduction, familiarity with a plant, and taste preference. Conversations with local Hawaiians about *Bidens* confirm these observations, which are also supported by the pharmacological literature, studies of modern Hawaiian ethnobotany, and other ethnobotanical literature that discusses the adoption of introduced plants into a pharmacopoeia.

If availability of a species is essential for its inclusion in a pharmacopoeia, then it becomes increasingly important to preserve the environments where indigenous people live and gather medicinal plants so that cultural knowledge about plant use may be preserved. If indigenous medicinal plants are not available, local healers will replace them with plants that are.

These conclusions about availability and biological activity of *Bidens* and *Plantago* in Hawaii are consistent with existing theories of medicinal plant selection. As Moerman (1998) suggests, the plants adopted are abundant (available), widespread geographically, and distinctive. (Although, contrary to Moerman's theories, neither species is very large nor perennial.) Abundant and widespread geographically, weed species (such as *B. pilosa* and *P. major*) are often highly competitive because they have high concentrations of active chemicals. This suggests that the factors that allow for their abundance and worldwide distribution also make them biologically active and thus effective medicine. Johns's (1990) work discussing indigenous observation and methodological techniques for selecting biologically active plants is also relevant to the discussion on how the Hawaiians selected plants with biological activity. Interviews with local Hawaiians illustrates that native healers are knowledgeable about comparative biological activity.

Whistler (1992), Davis (1995), Rivera and Obon (1995), Bennet and Prance (2000), and Paul (2002) all show the dynamic interaction of ethnomedical systems

with both the physical and cultural environment—how indigenous scientists experiment and adapt to meet the demands of changing social and environmental systems. While all of these studies mentioned the rapid adoption of new plant species when people are introduced into a new environment, Paul's (2002) work is interesting in that it supports the notion that new species of the same genera as known medicinal plants are more likely to be adopted into the indigenous pharmacopoeia. This research on *B. pilosa* and *P. major* supports that hypothesis; both plants could have been added because of the previous use of a similar plant in the precontact Hawaiian pharmacopoeia.

Whistler (1992) and Davis (1995) imply that the introduction of new disease, subsequent population decline, and other factors that accompany contact with European cultures encourage the addition of new plants to indigenous pharmacopoeias. This study, by examining two plants apparently adopted around 100–150 years ago, generally supports this hypothesis. However, it appears that neither *P. major* and *B. pilosa* were adopted to treat introduced diseases. A more general study looking at all the introduced species in the Hawaiian pharmacopoeia would be more appropriate to evaluate the larger effects of introduced diseases and migration on the pharmacopoeias.

While this research does not directly address the origin of the Hawaiian and Polynesian pharmacopoeias, the emphasis on the indigenous scientific process suggests that traditional herbal medicine did not arise solely after western contact. It suggests, rather that traditional knowledge of medicinal plants has a long history in Polynesia but was profoundly affected by the cultural, biological, and ecological changes that occurred with the arrival of Europeans in Polynesia.

Thus the discussion started by Cox (1991, 1995) becomes particularly important. The paradigm provides the pertinent questions and hypotheses that any group of scientists consider relevant. Science becomes the process of inquiry rather than the technological product. Ethnobiological research should, in realization of the importance of scientific paradigms, focus on understanding these processes. Studying the adoption of these introduced plants into the Hawaiian ethnopharmacopoeia, we can clearly observe the spiritual, pragmatic, active, and empirical processes involved in the science of *la'au lapa'au*.

By focusing on the introduction of two specific plants this paper clearly describes some of the processes behind substitutions. By studying plants that have been recently added to indigenous pharmacopoeias, insight is gained into the methodology of indigenous healers. This has significant implications for viewing ethnobotanical knowledge as dynamic and active in the context of cultural change. On a larger scale, examining the nature of change in Hawaii helps to understand the processes that continue to happen throughout the world as ecosystems are degraded and pharmacological traditions adapt to the changing realities of the twenty-first century.

NOTES

[1] Dharmananda, Suhhuti. n.d. A popular remedy escapes notice of Western practitioners. [www.itmonline.org/arts/bidens.htm] (verified September 2003).

[2] Interviews were carried out from January to April 2002. Having been raised in Ko'olauloa,

some of the people interviewed were already acquaintances. Through those I already knew I branched out and found others they recommended as having some knowledge about Hawaiian medicinal plants. The only people who considered themselves healers and who have active herbal medical practices were Bula Logan and Alapa'i Kahu'ena. The other interviews were with people who had widely differing experience with medicinal plants (personal experience while growing up, some formal training, etc.): their recollection and knowledge of the plants and their uses varied greatly. The participants were generally between 30 and 60 years old. Those interviewed were Gladys Ahuna, Millie Enos, Kawika Eskeran, Alapa'i Kahu'ena, Norman Kaluhiokalani, Bula Logan, Henry Na'awao, Howard K.K. Pali, Harold H. Pukahi, Rueben H. Pukahi, Kapua Sproat, Ipolani Thompson, Kamo'a'e Walk, and William Wallace. I would like to thank all of the people above who shared their knowledge and time in order help me better understand and appreciate *la'au lapa'au*.

[3] Voucher specimens were collected and identified by Clyde Imada at the Bishop Museum Herbarium and were deposited at the Waimea Arboretum and Botanical Gardens, 59-864 Kamehameha Hwy, Haleiwa, Hawaii 96712.

[4] Several of the people interviewed including Alapa'i Kahuena, Kapua Sproat, and Norman Kaluhiokalani had studied for some time under a well know Hawaiian healer, Papa Auwae. Much of what they knew came from their experiences with him.

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