Utilization of Biomass in Mediterranean-Type Ecosystems: A Summary and Synthesis[1]

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This session on the potential of Mediterranean-type ecosystems to supply biomass as a supplemental source of energy is a natural result of the present worldwide shortage of low-cost fuel. Some of these ecosystems are highly productive, partly because the summer drought is modified by dense fog which reduces the normal maximum air temperature to less than 25° C. Also, wet-season precipitation approaches 1000 mm. Biomass from such ecosystems is often used for sawtimber, and only residue is available for energy. At the other extreme of Mediterranean climate, marine air influence is low and the dry season is hot and nearly devoid of any form of precipitation. Under these conditions, most of the presently available methods of biomass processing may use as much energy as the biomass can provide.

By the definition of Mediterranean climate attributed to Koppen, precipitation in at least one summer month must be less than 3 cm and one or more winter month must receive at least three times the amount received in the lowest summer month. Also, the temperature of the coolest month must be between -3° C and 18° C and that of the warmest month above 10° C (Hidore 1969). Aschmann (1973) adds the conditions that total precipitation must be at least 275 mm at coastal sites and 350 mm at inland sites. His upper boundary is 900 mm. his intent seems to be to fit the definition to the chaparral zone of California.

In this summary of the papers presented in the session, some source material from other publications is included to clarify certain points. The summary begins with discussion of a few fundamentals of biomass production from 0echel. Methodology for measuring biomass is the second topic; the Pillsbury and Kirkley paper is the key source of information, with additions from Margaris, Toland, and Riggan and Dunn. We then shift to a discussion of technology for biomass utilization, drawing on papers by Toland, Riggan and Dunn, and Felker and others. Finally, for comments on the impacts of biomass removal, the Margaris, Riggan and Dunn, Felker and others, and Toland papers are primary source documents.

Recently, there have been many papers and at least five symposia dealing with biomass. A French review of forest biomass published in Forestry Abstracts (Parde 1980) identifies the "oil crisis" as one of three reasons for the current high level of interest in biomass. The other reasons cited by Parde are a significant shift in the timber trade and industry during the 1960's toward transactions in weight rather than volume, and an increasing tendency by scientists to measure biological productivity of forests as dry weight of plant biomass. Parde sees these three impacts as leading to scientific and technical upheaval. He points to an "explosion" of literature on the subject.

BIOMASS PRODUCTION

Vegetation managers are concerned about how much biomass is available. Basic physiological processes control biomass accumulation. Primary production starts with the assimilation of carbon, and an understanding of this process suggests some of the factors that control production. Oechel considers nutrients, moisture, temperature, and stand age to establish the groundwork for net production in biomass. Potential production is not equal among different shrub species. Of the species measured, chaparral whitethorn (Ceanothus leucodermis Greene.) has the highest potential photosynthesis rate, followed by seven other common chaparral species in California. The species with the lowest maximum photosynthesis rate is sugarbush (Rhus ovata Wats.).

Water stress is usually the most limiting factor in Mediterranean-type ecosystems. A key point in Oechel's analysis is that temperature is relatively unimportant in chaparral areas of southern California. Winter temperature is not low enough to suppress photosynthesis, and summer temperature is not so high that photosynthesis will be stopped. This, of course, does not mean that temperature would not otherwise control growth. Plant moisture stress can limit photosynthesis in several ways in addition to its direct effect. A plant's vascular system must deliver water from the roots to the leaves; if translocation cannot keep up with evaporation, the leaf stomata close so that photosynthesis slows and may nearly cease.

Conflicting information is available on the nutrient budget of chaparral species, according to 0echel. Nitrogen fertilization appears to depress the photosynthetic rate in greenhouse studies; photosynthesis increases when nitrogen is less available. However, nitrogen also affects patterns of carbon allocation, so that even though photosynthesis is depressed, a higher proportion of carbon may be allocated to growth. Consequently, fertilizing a stand of field-grown plants may show that adding nitrogen increases growth rate.

Plant age and stage of ecosystem development play an important role in determining biomass accumulation in chaparral and some other Mediter-

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ranean–type ecosystem communities. Biomass accumulation in chamise (Adenostoma fasciculatum H. & A.) is pointed out as an example of age dependence. Photosynthesis rates in resprouting chamise can be up to five times higher than in shoots on mature plants. Furthermore, Oechel makes an interesting (and frustrating) observation that although postfire sprouts show a marked increase in photosynthesis, sprouts from cut plants behave like the old vegetation and do not show enhanced growth. The information leading to this observation is from only one study however, and may not be conclusive.

Oechel identifies some outstanding problems for which answers are needed, regardless of how chaparral plant resources are used. First, the effect of harvesting on water relations and photosynthesis is complex and in need of study. Chaparral species appear to respond differently to burning and cutting. Mature plants use two–thirds of the carbon assimilated in photosynthesis for respiration, whereas sprouts use substantially less. The amount of stored carbohydrate is significant in promoting initial and subsequent sprout growth, but the processes controlling storage and availability for sprout growth are not well defined or understood.

METHODOLOGY FOR MEASURING BIOMASS

Hundreds of equations have been devised for calculating biomass yield. Parde (1980) notes that 137 new equations were added in 1979 to a list first issued in 1967; nearly all of these appeared after 1977.

Pillsbury and Kirkley (these Proceedings) summarize sources of information about hardwood biomass inventories in California. An interesting note is that the first hardwood inventory for California was published as recently as 1950, by the Forest Service. The others recognized by Pillsbury and Kirkley are from either Humboldt State University or California Polytechnic State University San Luis Obispo. In the past, lack of interest by other organizations was due to low demand for the resource and to the difficulty of obtaining precise inventory data. However, the level of interest is increasing and new techniques for inventorying hardwood are being developed. Good estimates are needed to clarify site–specific interrelationships.

Pillsbury and Kirkley recognize that the present need is to provide relatively gross inventory maps based on LANLSAT and U–2 remote sensing imagery. A cited paper (Griffin and Critchfield 1972) gives the range of hardwoods in California and urges completion of the inventory in these regions. Pillsbury and Kirkley also highlight the need to develop volume tables for each of the important species. They stress that stand management in California hardwoods runs the gamut from removing the hardwood to developing alternative land uses to directly managing; for the hardwood resource value.

Inventories of biomass and suitability of sites for harvesting have not been made for most of the noncommercial forests and shrublands in the United States. Without these data, the validity of proposals to harvest biomass are difficult or impossible to assess. Methods presently available limit where and how much biomass can be harvested because of yield, land surface features, and continuity of harvestable area. Margaris (these Proceedings) estimates that there is an average of 60 t/ha of standing biomass in the readily harvestable area of Greek maquis. Toland (these Proceedings) estimates a range of 22 to 78 t/ha on selected chaparral areas in California. An immediate problem is definition of a set of site conditions that specify present and near–future limits to harvesting. Inventories of biomass and site conditions should be made to standards that would provide the required information.

Much of the Mediterranean–type area is not sufficiently enticing to energy marketers to cause an insistent demand for areas to harvest. Parde (1980) gives one set of data showing aboveground productivity ranging from 6.5 to 15.5 t/ha/yr and another set showing annual increments of 1.2 to 7.4 t/ha/yr. Biomass accumulation in California chaparral is reported from several sources by Riggan and Dunn (these Proceedings). They show values ranging from 0.5 to 4 t/ha/yr. Schlesinger and Gill (1980) found that Bigpod ceanothus (Ceanothus megacarpus Nutt.) stands at 5, 12, and 21 years produced 3.3 t/ha/yr average accumulation of standing living and dead biomass. Living biomass growth in 12– and 21–year–old stands was 2.7 and 2.3 t/ha/yr, respectively (Schlesinger and Gill 1980, table 1). Certainly, these data for biomass accumulation are not comparable with those reported for coast redwood (Sequoia sempervirens [D. Don] Endl.) at 8.8 t/ha/yr at age 260 years or a Douglas–fir (Pseudotsuga menziesii [Mirb.] Franco.) stand that produced 4.27 t/ha/yr at age 375 years (Fujimori, in Parde 1980).

Usable biomass appears to be visualized as different amounts by various workers. Riggan and Dunn do not suggest a rule, but caution against removing foliage and fine stem material which contains the highest concentrations of nutrients. The biomass reported in their tables is whole stand plant material, however. Rockwood and others (1980) take a different view--branch and foliage biomass is "potentially unusable biomass." If data are to be of greatest value, criteria should be developed that will provide some standard breakdown of foliage, twigs, branches, and stems.

UTILIZATION TECHNOLOGY

Adequate technology for using biomass is missing but the papers by Toland and by Riggan and Dunn show development is occurring. Technology development in these low-producing ecosystems is slow because biomass is diffuse. Arguments such as those by Riggan and Dunn, which show how extensive an area of harvesting would need to be in order to supply a small city of 70,000 people, certainly seem valid. Except for certain very high yield sites, economic consideration appears to be an overriding problem. This may, on the other hand, be a shortsighted viewpoint. For example, the work of Miles (cited by Riggan and Dunn) suggests technology is capable of being improved beyond the clumsy plant cutters, tub grinders, and high—pressure pelletizers that Toland mentions in his paper. It is reasonable to assume that if the existence of a significant renewable resource is demonstrated, technology will be developed to obtain and process that resource. Pimentel and others (1981) analyzed the potential for using residues following harvesting of crops and forests; they conclude that 4 percent of the electrical energy now used in the United States could be supplied from processing 22 percent of the harvest residues for energy.

The energy shortage is expected to get worse. Hafele (1980) suggests that per capita energy available by the year 2030 may be 1 kW per year compared with 2 kW per year in 1980. He cites studies indicating that such a scenario is likely even if energy resources increase above present levels. Population increases alone will cut energy supply in half.

Biomass, especially on the most productive sites, contains considerable energy. Where aboveground biomass is 50 t/ha, Riggan and Dunn calculate a gross energy equivalent of 182 barrels of oil. Chaparral harvesting is therefore being actively considered. Riggan and Dunn note that a University of California engineering feasibility study reported by Riley and others concludes that harvesting and processing costs are prohibitive. The current technology referenced by the University of California study is rapidly changing, however. When only 17 percent of the gross energy (Riley and others) [3] is consumed in harvesting and initial processing, there is good reason to believe that a way will be found to extract the remaining energy. Riggan and Dunn report that one southern California National Forest Ranger District receives about 3000 firewood requests each year, but only a small part of this number are granted. These authors conclude that the ongoing effort to find ways to harvest chaparral and associated woodlands makes it imperative that we know what the environmental implications will be.

Margaris confronted the problem of energy harvesting in Greece by suggesting a rotational type of harvest. Energy in Greece is an even more immediate and serious problem. Margaris reported that gasoline sells for $0.85 (U.S.) per liter. This compares to $0.40 or less per liter of unleaded gasoline in most of southern California. Margaris suggests that maquis can be harvested on a sustained—yield basis once each 10 years. The area suggested for harvesting is sufficiently level to allow for harvesting by current equipment and technology. On such a continuing basis, yield of maquis would be 80 percent of maximum. Mediterranean—type ecosystems cover about 40 percent of Greece and maquis dominates about one—half of these ecosystems. Maquis accounts for about 80 percent of the aboveground plant biomass in the Greek Mediterranean—type ecosystems. Maquis areas found on "level ground" make up about 10 percent of the land surface area of Greece. Margaris estimates that harvesting this amount of land would yield biomass containing energy equal to about 40 percent of the current Greek oil imports.

Toland discusses the problem of energy harvesting in a general way, stating first that the Forest Service has establishel5a national goal of providing 6.4 quads (1.6 x 10^{15} kcal or 6.4 x 10^{15} Btu) per year from woody biomass by 1990. The biomass contribution of the Pacific Southwest Region is from an estimated 23 million t/yr or about 0.4 quads of energy.

Toland recognizes that current economic efficiency is unfavorable for developing wood biomass energy, but sees that picture as changing. Significant improvements in technology is likely to make use of wood biomass an attractive alternative. At present, potentially commercial harvest from sources such as chaparral could be subsidized to reduce costs of fire and postfire erosion. Lack of adequate technology for biomass removal is probably the major deterrent to harvesting, but even with present technology, biomass removal for energy from highly productive areas is occurring.

Toland also discusses various means of harvesting and processing. Each seems to need major improvements if the shrub biomass is to be accommodated. Use of forest slash appears to be already an acceptable practice where very large quantities are available. The most obvious use of biomass, Toland reports, is for direct combustion; also noted are use for updated techniques of gasification, to produce low Btu gas (1353 $kcal/m^3$); use for pyrolysis, to convert woody biomass to oil, gas, and char; and use as feedstock, to produce chemicals, including alcohol. More sophisticated forms of these processes are being developed, but it is unlikely that any will be used unless biomass produced is the highest available quantity and quality to assure efficient processing. Certainly, chaparral and other shrub types are unlikely candidates for energy contribution at present.

Toland suggests that consideration be given to converting chaparral brushfields to product—specialized species such as guayule (*Parthenium argentatum* Gray) or jojoba (*Simmondsia chinensis* [Link] C. K. Schneid.). The potential for these product—oriented species has had little research emphasis. Species screening for such specialty production is not new, especially for forage, human food, drugs, and other fiber. Pillsbury and Kirkley report continued interest in developing

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[3] Riley, John G., Samad Moini, and John A. Miles. An engineering study of the harvesting and densification of chaparral for fuel. 1980. Unpublished draft.

better understanding of hardwood site quality relationships. They also suggest a plantation approach to fast–growing, fiber–producing trees as alternatives or in addition to native hardwoods.

In their paper, Felker and others (these Proceedings) effectively illustrate the problems of selecting and testing highly productive species. Mesquite (Prosopis spp.) is an excellent plant from which to make genetic selections for high fiber production and for other specialty products. Species of mesquite are found in hot climates, commonly associated with desert areas, but do require substantial amounts of water to be productive. Felker and others also report that mesquite species tested were hosts of nitrogen–fixing nodules. These nodules were most effective below 2.7 m in a phreatophyte greenhouse test. In this experiment, water entered the rooting zone from below the 3.05–m soil column as it would in a desert streambed. Another interesting and potentially very useful trait is the ability of several mesquite species to tolerate high salinity levels. These plants even grew slightly where salinity was comparable with seawater. One test showed growth at 36,000 mg NaCl per liter of water.

IMPACT OF BIOMASS REMOVAL

Although, in Greece, according to Margaris, and possibly in some of the other Mediterranean–type ecosystem areas, the impact of biomass removal is slight, in California it could have serious negative effects. Probably more concern is properly placed on ecosystem stability following harvesting in southern California. Stark's (1980) work shows the potential for serious nutrient loss associated with biomass removal. her studies were in Montana, where she worked with the nutrient budget in a Douglas–fir (Pseudotsuga menziesii)/blueberry (Vaccinium caespitosum Michx.) habitat type. From measurements of nutrient movement out of the root zone and also, apparently, on effects of removal of nutrients from the forest, she concludes that biomass removal should be restricted to large stems and branches, and that twigs and foliage should be left on site. Stark brings attention to the fact that balance among nutrients must be a major concern.

Riggan and Dunn (these Proceedings) note that harvesting may be aimed at either permanent fuel modification or sustained yield in energy management areas. They suggest that type conversion has serious environmental hazards, which could be prohibitive in large parts of southern California ecosystems. Both site stability and productivity could he seriously affected. Comments from both Felker and others and Toland seem to suggest that alternative species of woody plants may be desirable to a chaparral ecosystem and provide products that satisfy some highly specialized human needs. on the other hand, Toland, and Riggan and Dunn, caution that type conversion aggravates the problems of erosion and related massively destructive flooding from denuded steep watersheds in some areas of Mediterranean–type climates. Type conversion as a way of producing significant harvestable biomass for energy seems to offer minimal opportunity even if species of very rapid growth are used. Adequate production would be possible on few sites and even these would probably require supplemental water. Other uses of such land and water resources would probably be of higher priority.

The alternative approach to the Mediterranean–type climate ecosystems for energy biomass, sustained–yield management, presents some problems that must be seriously considered. Riggan and Dunn discuss the opportunities and damages related to reduced fire hazard, plant community composition changes, and nutrient loss. Nutrient removal may become severe if the entire aboveground biomass is removed. Fire hazard may be worsened by either the harvesting operation itself or the encouragement of species that produce more highly flammable debris. Riggan and Dunn chart the life history of southern California chaparral and identify species significant in stand development. Many of these species can support symbiotic nitrogen fixation, and their persistence may be essential to site and stand stability. Loss of robust and tall species of Ceanothus or Quercus is likely to encourage establishment of species that mature more rapidly, produce more flammable fine fuel, and have more shallow root systems. Riggan and Dunn identify black sage (Salvia mellifera Greene.) and buckwheat (Eriogonum fasciculatum Eenth.) as two such less desirable species.

CONCLUSIONS

Each author represented in the session has an individual emphasis on what constitutes Mediterranean–type ecosystems; most seem to feel the ecosystems are dominated by shrublands. I do not agree with that conclusion. Ecosystems found in Mediterranean climates include some conifer communities, as well as hardwood forests and shrub–lands. The climate is characterized by wet winters with an upper bound of at least 900 mm of rain and by rainless summers. The coldest month is between -3° C and 18° C.

The range defined by the above climate conditions includes marginally desert climate but stops short of the summer rainfall areas. When yield is below 60 to 75 t/ha, harvesting technology for biomass use must he more efficient than that now available. Apparently, there is more opportunity to use low–yield areas in Greece and other developing countries than in California. At least three criteria for evaluation seem appropriate. The first is energy efficiency, and asks how much energy is used to obtain the energy in biomass. If 17 percent of the residual energy in biomass is used to harvest and process it into fuel (Riley and others[3]), how efficient must the remaining processes be? If the answer is a value comparable to that for equally available resources, the next questions are environmental and economic.

From the papers in this session, it is clear that we do not know how efficient biomass processing must be, how the return on dollars invested can be made adequate, or how acceptable the environmental impact can be made. Biomass quantities and quality are unknown. Even for high—yield conifer timber areas, we do not know total biomass.

The Old World countries in the European Mediterranean have long demonstrated the results of unwise biomass utilization. The papers presented indicate that we do not understand any of the ecosystems well enough to make reasonable predictions about the effects of mechanically removing the entire vegetation biomass of the ecosystem. We have reasonably good understanding of the effects of removing vegetation by fire, and some knowledge of the impact of vegetation type conversion. If mechanical removal of vegetation is repeated often enough, then research and experience with type conversion may apply, but no research is known on mechanical removal in the 20— to 46—year rotation suitable for a harvesting program.

LITERATURE CITED

Aschmann, Homer. Distribution and peculiarity of Mediterranean ecosystems. In: di Castri, Francisco; Mooney, Harold A., eds. Mediterranean type ecosystems: origin and structure. New York: Springer—Verlag; 1973: 11—19.

Griffin, James R.; Critchfield, William B. The distribution of forest trees in California. Berkeley, Calif.: Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1972; Res. Paper PSW—82. 114 p.

Hafele, Wolf. A global and long—range picture of energy developments. Science 209:174—182; 1980 July.

Hidore, John J. A geography of the atmosphere. Wm. C. brown Co. Publ.; 1969. 106 p.

Parde, J. Forest biomass. For. Abstr.; Commonw. For. bur. 41(8):343—362; 1980 August. [English translation by Sinclair.]

Pimentel, David; Moran, Mary Ann; Fast, Sara; [and others]. Biomass energy from crop and forest residues. Science 212:1110—1115; 1981 June.

Rockwood, U. L.; Conde, L. F.; Brendemuehl, R. H. Biomass production of closely spaced Choctawhatchee sand pines. Asheville, N.C.: Southeastern Forest Exp. Stn., Forest Serv., U.S. Dep. Agric.: 1980; Res. Note SE—293. 6 p.

Schlesinger, William H.; Gill, David S. Biomass, production, and changes in the availability of light, water, and nutrients during the development of pure stands of the chaparral shrub, Ceanothus megacarpus, after fire. Ecology 61(4): 781—789; 1980 August.

Stark, N. Changes in soil water quality resulting from three timber cutting methods and three levels of fiber utilization. J. Soil and Water Conserv. 35(4):183—187; 1980 July/August.