# Developing a Drying Schedule for a “New-to-You” Species[1]

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## Introduction

The lumber dry kiln operator’s workday is rarely boring. Anyone that thinks the job is to sit back and watch wood dry will not last long in the business. In addition to operating one or more dry kilns, the job requires the ability to schedule lumber flow through the batch drying process so mill production goals are met, as well as a thorough understanding of steam systems, steam traps, lumber quality, manual and computerized sensors and controllers, and perhaps most importantly…how to recognize when something is going wrong and fix it before the lumber charge in a kiln is ruined. Through years of experience and training, successful kiln operators become very accomplished at these tasks. Most kiln operators work with a small handful of commercial species and over time they have developed a thorough understanding of the specific drying characteristics of these woods. Occasionally, a kiln operator may be faced with the task of drying a species without any prior knowledge of its characteristics. In other words it is a “new-to-you” species. The following discussion describes a procedure for approaching this problem and determining a drying schedule to maximize the chance of success on the first try.

A good example of this scenario can be based on western hardwoods. Consider the situation where a kiln operator has worked at the same sawmill for 10 years drying the same three softwood species and one day the supervisor relays the message that the company is going to cut 1 million board feet of tanoak (*Lithocarpus densiflorus*) next week and no one in the company has every dried it before. Could it happen? It has happened in the past and it will surely happen in the future. Consider this.

There is a sizable hardwood component to California's forests. Despite this, the native hardwoods never played an important role in the products produced from the forest. Traditionally, these hardwoods have also been a source of food (nuts and acorns), wildlife habitat, timber for local farm and home use, and firewood—all of little commercial value. Today the major uses of hardwoods in California are for fuel chips, pulp chips, and firewood, all products that return little value to the landowner. As we move through the 21st century, an increasing understanding of the science of ecology and societal pressures are causing a reevaluation of our natural resources with an emphasis on sustainable production and improving rural economies. In certain situations hardwoods

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may be a viable resource for local needs, specialty products, or perhaps even supply a larger commodity market. Of the western hardwoods, the high-density hardwoods such as tanoak, madrone, California black oak, and the white oaks have recognized potential for value-added products but still remain largely underutilized, in large part because of the difficulty of drying the lumber produced from this species.

Hardwood species in California total more than 5 billion cubic feet of growing stock volume and about 60 percent of it is located in the timberland forest where it makes up about 10 percent of the standing timber inventory (Bolsinger 1980). California is also one of the nation’s major consumer markets for hardwood products such as flooring, furniture, and cabinets. Manufacturing these products near the markets offer distinct economic advantages in low transportation costs. However, of more than one hundred million board feet of hardwood lumber used in California per year less than 5% comes from the western species (Shelly 1995).

The high-density western hardwoods have a reputation for being difficult to dry. Little experiential knowledge exists for drying these species but with an understanding of basic wood properties and appropriate drying procedures good results can be obtained even with the most difficult-to-dry species (Hall 1998). So as a kiln operator faced with the challenge of drying a “new-to-you” species, what do you do first?

## Define the Problem

The first thing to do is to find out as much as you can about the wood you intend to dry so you can better understand the wood will behave during drying and develop an appropriate schedule. Check your reference books and ask around to gather information in the following 4 steps.

- Find out what you can about the properties of the wood
    - Density (specific gravity)
    - Cell structure
    - Green moisture content
- Determine what drying defects are likely
- Look for documented dying schedules and results
- Ask opinions of other kiln operators and wood technologists

## Wood Properties

With knowledge of the physical properties of a wood species it is possible to predict the general behavior of the wood and to identify potential problems that may arise. Of all the physical properties that can be measured, density (often reported as specific gravity) is the most important to understand how the wood will dry. Density is a good predictor of the level of drying difficulty, the magnitude of dimensional change (shrinkage or swelling) expected in response to changes in wood moisture content, and the potential to warp. For the purposes of this discussion, high density species are defined as those with a specific gravity determined on an oven-dry mass and green volume basis of 0.5 or greater. These high-density species are generally more difficult to dry and less dimensionally stable than species with a lower density (specific gravity less than 0.5).

As a general rule, high-density hardwood species also exhibit greater dimensional change and have a greater tendency to warp and collapse during drying than low-density hardwoods. The exceptions to this rule are tropical hardwood species that are often very high density but exhibit low values of dimensional change. Hardwoods prone to warp are those that have a tangential shrinkage (tangent to the growth rings) greater than 10% and a warp index (the ratio of tangential to radial shrinkage) greater than 2.0. Collapse on the other hand is not as clearly related to density. There are some very high-density woods that are very prone to cell collapse during drying but there are other high-density woods that do not collapse. In hardwoods, collapse is most likely to occur in wood cells that are saturated with water when drying begins. Hardwoods that have a very high green moisture content (above 80%) will have more saturated cells and as a consequence they will be more likely to exhibit collapse. Table 1 lists these physical properties for some of the more important western hardwood species.

**Table 1. Basic physical properties for western US hardwoods.**

| | SG | Green MC[1] | Tang. Shrnk[2] | Warp Index | Drying comments |
|---|---|---|---|---|---|
| Red Alder | 0.37 | 98 | 7.3 | 1.7 | Easy to dry, prone to discoloration |
| Bigleaf Maple | 0.44 | 72 | 7.1 | 1.9 | Easy to dry, prone to discoloration |
| CA Black Oak | 0.48 | 105 | 7.8 | 2.1 | Moderately difficult to dry, prone to stain and checking |
| Oregon Ash | 0.50 | 49 | 8.1 | 2.0 | Moderately difficult to dry, wet pockets |
| Madrone | 0.57 | 80 | 13.7 | 2.4 | Difficult to dry, prone to collapse |
| Tanoak[3] | 0.60 | 91 | 12.0 | 2.0 | Difficult to dry, prone to collapse and stain |
| OR White Oak | 0.72 | 70 | 9.0 | 2.1 | Difficult to dry, prone to collapse |

[1] green MC reported in Niemiec et.al (1995)
[2] shrinkage values from Wood Handbook (Anon 1999)
[3] tanoak values from Shelly (2001)

## Drying Defects

Defects that appear during the drying of wood can be grouped into three categories defined by the origin of the defect and the mechanism by which it is formed. These three categories are:

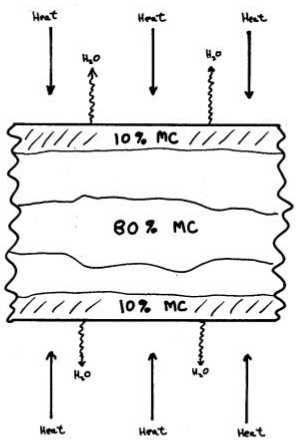
- Growth Related
    - Shake – a separation along the growth rings
    - Warp – deviation in straightness related to grain angle, sawing pattern, and the presence of reaction wood
- Stress Related
    - Surface checks and end checks
    - Honeycomb – internal checks perpendicular to growth rings
    - Collapse – cell collapse causing uneven thickness and wavy surfaces
    - Casehardening – internal stresses causing distortion when wood is resawn
- Discoloration

- Biological (stains caused by decay, bacteria, etc.)
- Chemical (oxidation of enzymes and extractives)
  - Sticker stain, mineral streak, iron stain, kiln brown stain, etc.

With the exception of shake and biological discolorations, these defects can be at least partially controlled by the drying schedule, and all are at least in part related to stresses that develop as the lumber dries.

The stresses that cause lumber to warp are a direct result of the inherent differential shrinkage that occurs in wood across the grain, that is, between the tangential (tangent to the growth rings) and radial directions (parallel to the rays), or natural or saw-induced grain deviation within a board. Drying lumber in thicker dimensions or placing a uniformly distributed dead weight restraint on the boards to keep them flat during drying can minimize warp. Also, narrow boards will warp less than wider boards.

Drying defects occur because stresses are created inside wood as the water leaves and the wood shrinks. If these stresses are large enough, they can cause defects such as checks, honeycomb, casehardening, and collapse. Although most of these defects are not apparent until the wood is nearly dry, they actually begin to develop very early in drying when the shrinkage of a dry shell is restrained by a wet core in a swollen state (Figure 1). During the first stage of drying cell collapse begins as the free water inside of saturated cells is removed. Drying stresses begin in stage 2 when the outer shell of the wood begins to dry. The faster the wood dries in stages 1 and 2 the greater the stresses will be, and as a result the more likely drying defects will occur. In stage 3 the inner core dries below the fiber saturation point (about 25% MC). If a drying defect is going to appear it will happen in this stage.



Wood dries from the outside in, creating moisture gradients that lead to drying stresses and potential defects.

Stage 1 – free water removal
  a. stress free
  b. cell collapse

Stage 2 – shell in tension, core in compression
  a. surface checks
  b. collapse

Stage 3 – shell in compression, core in tension
  a. honeycomb
  b. caseharden

**Figure 1 – How stresses develop during drying and the defects they cause.**

The critical stage is from the initial green MC (when the lumber is first cut from a fresh log) down to about 25%. The difficult to dry species have a tendency to develop collapse and honeycomb if they are dried too fast during the critical stage. It is important to dry them slowly (2% - 3% MC decrease per day) at low temperatures and a high relative humidity (below 110° F and above 85% RH) until a wood MC lower than 25% is reached.

**Drying Schedules**
With knowledge of wood characteristics, drying principles and adequate control over the drying conditions, a process can be developed to produce quality dry lumber for your "new-to-you" species. Important details that need to be considered when developing the drying schedule are listed in Table 2.

**Table 2. Wood Characteristics and Drying Recommendations**

| Wood Characteristic | Recommendations | Special Concerns and Trade Offs |
|---|---|---|
| Density ($Sg_{o,g}$) greater than 0.5 | Stages 1&2 mild schedule, (RH) (relative humidity) above 90% | Monitor for collapse, stress-induced defects, and stain |
| Warp prone | a. Use mechanical restraint, keep lumber flat during drying | |
| | b. Stage 1&2 rapid drying of shell | Increases potential for stress-induced defects |
| Stain prone | a. Stage 1&2 rapid drying of shell with T above $120^{o}$ F and RH below 80% | Increases potential for stress-induced defects |
| | b. Stage 1&2 rapid drying of shell with T below $80^{o}$ F and RH below 60%, good air flow | Difficult conditions to control in a dry kiln, may need to air-dry |
| Collapse prone | Stage 1 mild schedule, RH above 90% | Monitor for stain |
| Stress-induced defect prone | | |
| end checks | Stage 2 mild schedule, end seal | Monitor for stain |
| surface checks | Stage 2 mild schedule | Monitor for stain |
| honeycomb | Stage 2 mild schedule | Monitor for stain |
| casehardening | Stage 2 mild schedule, conditioning | Monitor for stain |

A mild schedule for stages 1 and 2 is defined as a combination of temperature and humidity that will produce a drying rate for 1-inch thick lumber that does not exceed a 2-3% decrease in MC per day. A moderate schedule will produce a drying rate of 3-6% decrease in MC per day, and a severe schedule will dry wood at rates as high as 20% decrease per day. Once out of stages 1 and 2 and the MC reaches about 25% (drying stage 3) then the drying temperature can be increased and the RH decreased dramatically to shorten the overall drying time without danger of creating additional defects. the conditions can safely be used.

If the wood characteristics indicate the need for mild drying in the critical drying stages 1 and 2, then air-drying can be an effective method if the long drying times are not a concern. However, it is possible that the drying conditions can be too severe in an air yard. If this is the case then it may be a better idea to put the lumber directly into a kiln. Although it is believed by some that difficult to dry hardwoods must be air-dried before they are put into a kiln, this is generally not the case. All hardwoods can be dried from the green condition in a kiln if the recommended conditions can be controlled.

## The Tanoak Example

Tanoak (*Lithocarpus densiflorus*) is a high-density hardwood (SG = 0.60) with a high green moisture content (heartwood MC of 90+ %) and a reputation of being difficult to dry. Collapse and honeycomb are very difficult to avoid in this species and it is considered by many to be too difficult to work with to be a commercial species. However recent studies indicate that the wood can be successfully dried and used to produce high value products (Shelly 1995, 2001).

A review of drying schedules used by others in the past revealed that high levels of stress-induced defects resulted from these schedules suggesting that modifications were needed (Table 3).

**Table 3. Comparison of Published Tanoak Drying Schedules.**

| | Kiln Operators Manual (schedule T3, B1) | | Espenas (1953) | | Shelly (2001) | |
|---|---|---|---|---|---|---|
| MC | DB[1] | WB[2] | DB | WB | DB | WB |
| 80 | 110 | 107 | 105 | 102 | 80 | 70 |
| 50 | 110 | 107 | 105 | 102 | 90 | 85 |
| 45 | 110 | 107 | 110 | 104 | 90 | 85 |
| 40 | 110 | 107 | 120 | 109 | 90 | 85 |
| 35 | 110 | 106 | 120 | 109 | 90 | 85 |
| 30 | 120 | 114 | 130 | 109 | 100 | 95 |
| 25 | 130 | 120 | 130 | 109 | 110 | 100 |
| 20 | 140 | 115 | 130 | 109 | 120 | 100 |
| 15 | 160 | 110 | 180 | 130 | 135 | 110 |
| 10 | 160 | 110 | 180 | 152 | 140 | 105 |
| 8 | 160 | 110 | 180 | 152 | 140 | 100 |
| Results | heavy collapse, heavy honeycomb | | heavy collapse, heavy honeycomb | | moderate collapse, heavy stain | |

[1] DB = dry bulb temperature

[2] WB = wet bulb temperature

The schedules from the Kiln Operators Manual (Simpson 1991) and Espenas (1953) both resulted in unacceptable levels of collapse and honeycomb. Based on this information, Shelly (2001) modified the schedule to achieve milder drying conditions and hopefully reduce the amount of collapse and honeycomb. The schedule was successful in reducing honeycomb, but collapse remained high and also the low initial temperature and high relative humidity created ideal conditions for a chemical kiln-induced stain of the wood (Figure 2).

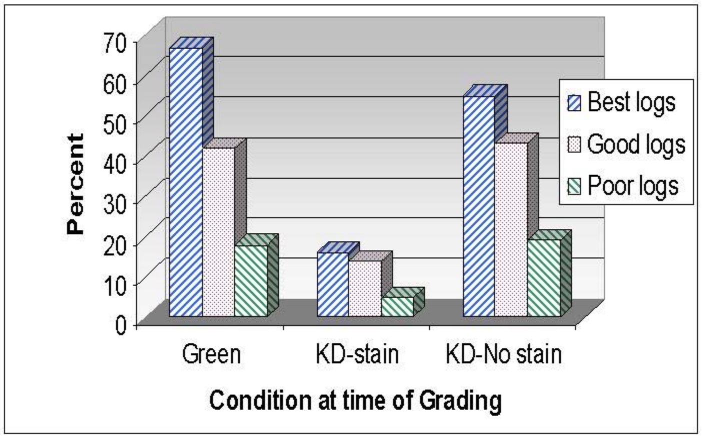
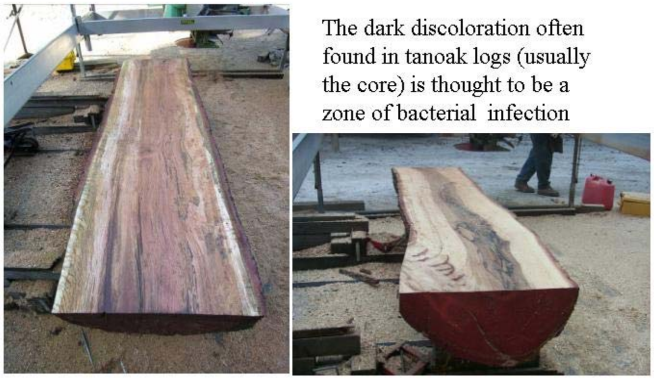


**Figure 2. The Shelly (2001) Moderate Kiln Schedule Produced a High Level of Stain Resulting in Unacceptable Downgrade.**

The yield of high-grade (No. 1 Common and Better) green lumber from the tanoak study logs was similar to yield expected for commercial eastern hardwood species. However, when the lumber was dried the percentage of high-grade lumber from the best logs dropped from 67 percent to 16 percent when the National Hardwood Lumber Association grading rules were applied which consider stain a defect. If the stain was ignored then the drop in high-grade lumber for the best logs was from 67% to 55%, approaching an acceptable amount of degrade in hardwood kiln drying. The major defect, ignoring stain, was collapse. Clearly, a drying schedule was needed that would minimize the formation of the kiln stain and cell collapse.

It was also noted during the drying tests that drying degrade was greatest in the lumber produced from the older, larger trees in the study. A strong correlation was noted between the amount of collapse in the lumber produced from these trees and the high frequency of “mineral streak or heart stain”, a zone of dark reddish/brown discoloration in freshly cut lumber (Figure 3). In follow-up drying studies the high incidence of collapse in this “heart stain” region could not be avoided no matter how mild the drying conditions were. Based on these observations it is recommended that lumber not be produced from the heart stain zone.



The dark discoloration often found in tanoak logs (usually the core) is thought to be a zone of bacterial infection

**Figure 3. Heart Stain in Tanoak Logs**

Although mild drying conditions during stage 1 drying will minimize the amount of cell collapse that develops during kiln drying, it is very difficult to eliminate the collapse defect in a highly prone-to-collapse species such as tanoak. A series of tests are in progress that compare the amount of collapse produced in tanoak that was air dried for varying lengths of time before it was kiln dried with a mild schedule (Shelly 2005). As presented in Figure 4, lumber that was air-dried for at least 4 months resulted in the highest number of boards without collapse after kiln drying (72% without collapse). The lumber that was kiln dried without any air-drying time had the fewest number of kiln dried boards without cell collapse and the highest number of boards with cell collapse.

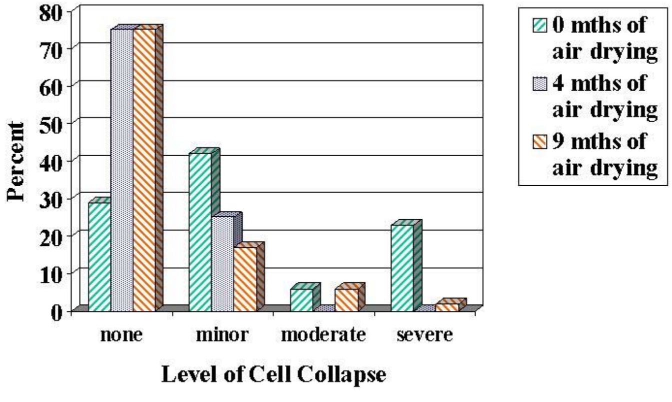


**Figure 4. The Effect of Air Drying on Collapse**

Although air drying the tanoak lumber before kiln drying seems like a reasonable approach from the point of view of minimizing collapse it is likely that air drying could increase the amount of kiln stain if the air-drying conditions are in the range of 85$^{o}$ to 90$^{o}$ Fahrenheit and 80% relative humidity or greater. The lumber from the collapse study described above was also examined for kiln stain after it was kiln dried. The results reported below in Figure 5 revealed that the amount of stain developed was highest for the lumber that was air-dried for 4 months and lowest for the lumber that air-dried for 9 months. However the kiln stain in the lumber that air-dried for 9 months was not much different than the lumber that was kiln dried without any air-drying. This suggests that the conditions that the lumber is exposed to during air-drying, which cannot be controlled, may be conducive to initiating kiln stain. A probable explanation for this is that the drying conditions are influenced by the weather conditions. If the lumber is air-dried when conditions are not conducive to the stain then it will not occur. However is humidity remains high for a period of time when the surface of the wood is wet than the stain is likely to occur. Based on this observation and the previous observation that the kiln stain is a very serious degrade factor for tanoak, it is recommended that air-drying for tanoak lumber not be initiated during periods of high humidity.

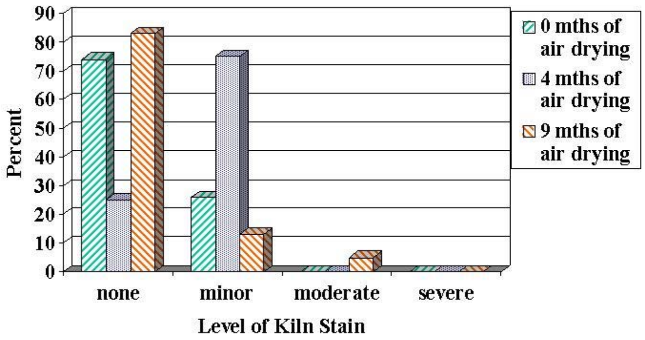


**Figure 5. Air Drying Effect on the Development of Kiln Stain**

## Summary

Tanoak has the potential to be an important hardwood resource. By applying knowledge of the tanoak wood properties with basic principles of drying a drying schedule was developed that could produce an acceptable quantity of kiln-dried tanoak lumber. The potential for collapse, honeycomb, and kiln stain emphasize the need to follow the appropriate schedule and the importance of following good drying practices cannot be overemphasized. The following recommended drying practices were compiled by applying the results of the analyses discussed above with generally accepted good drying practices.

1. Process logs into lumber as quickly as possible because stain is more likely in logs stored longer than 1 month.
2. Fresh cut lumber must be stacked immediately on stickers to start the drying process.
3. Segregate lumber by species, thickness, and heart stain.
4. Stack the lumber with strong, dry stickers of a uniform thickness (3/4 or 1 inch thick by 1-1/4 inch wide). Lumber dries faster with thicker stickers that allow more air movement through the stack.
5. Align stickers vertically so that the weight of each board is carried by the load supports.
6. Seal the end grain of each board with a paraffin-based end sealant to reduce end checking. Commercial end sealers are available, check with forestry and lumber manufacturing suppliers.
7. Monitor the MC of sample boards during drying.
8. The initial drying conditions (for at least the first two weeks of drying) should encourage good circulation of air at a temperature between 75 and 80 degrees Fahrenheit with a relative humidity below 60 percent. This can be accomplished in either air-drying or kiln drying methods. It is important to keep the temperature below 80 degrees Fahrenheit to minimize drying-induced chemical discoloration.
9. Follow the recommended schedule presented in Table 4 that is designed to minimize cell collapse.
10. Dry to a target MC suitable for your customer's needs.
11. Check for casehardening and condition the lumber if necessary.
12. Check for honeycomb and collapse. A customer surprised by these defects will probably not be a repeat customer.
13. Store dried lumber in flat, solid stacks (no stickers) in a closed shed; a heated shed is ideal.
14. Re-check the MC of the lumber before it is used or sold; you may need to re-dry it. Lumber at 8% MC will gradually increase to the equilibrium moisture content (EMC) of its environment (about 14 - 16% MC in unheated storage shed near the coast or about 10 -12% in most inland locations).

**Table 4. Recommended Drying Schedule for 1 to 2 Inch Thick Tanoak Lumber**

| **Step** | **Moisture Content** | **Temperature (dry bulb)** | **Temperature (wet bulb)** | **Relative Humidity** |
|---|---|---|---|---|
| 1-predry | Above 50% MC (critical zone) | 70° F | 60° F | 55% |
| 2 | 50% to 30% (critical zone) | 80° F | 70° F | 61% |
| 3 | 30% to 25% (critical zone) | 100° F | 95° F | 85% |
| 4 | 25% to 20% | 110° F | 100° F | 70% |
| 5 | 20% to 15% | 120° F | 100° F | 50% |
| 6 | 15% to final MC | 140° F | 110° F | 38% |
| 7 | Equalize as needed | 140° F | 105° F | 55% |
| 8 | Condition as needed | 140° F | 132° F | 80% |

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